The No Chico Brush Partnership

A farmer-led initiative for capacity building, demonstration and evaluation and research on efficient irrigation approaches in the Gunnison Basin

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In addition, this project was supported and sponsored by participating agricultural producers, associated professionals and volunteers, along with Colorado State University (through its Water Center and Extension Service) and the Colorado River District.

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Further information is available at http://gunnisonriverbasin.org/projects/no-chico-brush/

Executive Summary

Gunnison Basin Predicament

Like across most of the arid West, irrigated agriculture in the Gunnison Basin faces a predicament posed by competition for limited water resources. As identified by the Gunnison Basin Roundtable and the Colorado Water Plan, the current gap between demand and supply for water in the Gunnison River Basin for agricultural sector is estimated to be an average of 116,000 acre-feet per year (Colorado Water Plan, 2015).

This predicament affects irrigators and agricultural producers in the Gunnison River Basin, who struggle to meet their crop demands with available water supplies in most years. This issue is exacerbated by the uncertain future that will be marked by increasing demands and diminishing supplies of water due to observed and projected warming, along with market conditions that fluctuate dramatically without warning.

To some producers, the challenging situation has been expressed as "farming for self-defense." Put a little differently, irrigated farming has, in some areas, become a 'defensive strategy' to be used to fend off intra-state and inter-state competitive pressures for limited water supplies and productive land. This defensive attitude represents a dramatic shift from the long heritage and the once-secure ideal that irrigated agriculture is a permanent part of the landscape, essential to the aesthetic, culture and economy of the region.

Now, water availability and water quality challenges drive the search for creative approaches and adaptation strategies to be undertaken by producers to shift away from 'self-defense' and survival mode. To do this, a balance between agricultural water supplies and demands is needed to sustain productivity; at the same time additional pressures from non-consumptive uses, posed by recreationalists and environmental needs, must be met.

Even with creative and flexible thinking, along with modernized irrigation practices, the central question remains: what does a sustainable irrigated agricultural system look like?

Conventionally, agricultural water conservation programs have been used to address water shortages. In recent years, these conservation programs have moved away from the approach of permanent fallowing of productive farmland, known colloquially as "buy and dry," after some disastrous experiences in Crowley County, Colorado, the Owens Valley, California and elsewhere in the west. Now, with permanent fallowing out of favor with farmers and the public alike, agricultural water conservation has generally shifted to partial or rotating fallow programs., The "Super Ditch" in the Arkansas River basin (Nichols *et al*., 2016) and the System Conservation Partnership Program (UCRC, 2018) are examples of this approach. These newer agricultural conservation efforts have moved towards the concept of temporary, voluntary and compensated "lease and cease" processes. However, such temporal programs must address significant concerns about long-term effects on rural economies, labor impacts, cropping patterns and genetics, agronomics, markets, and financial institutions that support the agricultural industry. Such studies are on-going (CRD, 2020)

In pursuit of alternatives, approaches and solutions to the described predicament, the leaders of the No Chico Brush partnership put together this research project that emphasized 1.) the quantification of site-specific crop water needs and on 2.) defining efficient irrigation methods and timing that can garner higher margins and investment returns. The project focused upon quantifying the benefits associated with increased irrigation water management using sophisticated monitoring and efficient irrigation technology.

Overall, the No Chico Brush project served to demonstrate a pathway to a sustainable water balance guided by optimal management and cooperative investment in technology that results in increased productivity and profitability using less water. Proponents are hopeful that the findings and associated flexibility would enable related agricultural water conservation practices and programs. This could include, but not be limited to, demand management through potential temporal leasing-fallowing, deficit irrigation and other techniques. Furthermore, that such programs could also enable the implementation of soil health, water quality improvement and water supply availability in the context of a comprehensively and holistically managed framework.

The No Chico Brush Partnership

The No Chico Brush Partnership, or "No Chico Brush" (NCB), as it has become known locally, was formed in 2011 to support communication, demonstration and research on sustainable agriculture in the Lower Gunnison River Basin. This project originated with local producers in the Delta and Montrose Counties, who were seeking viable alternatives to minimize legal, climatic and economic threats to their water supplies. Building on local interest in soil health, the group saw the need to further evaluate water use as part of the adaptive strategy for the irrigated agriculture community in the Gunnison Basin. The costs and benefits of newer and more efficient irrigation technology, best management practices (BMPs), and alternative water management techniques are NCB priorities to define, develop and to share.

As a farmer-led group, NCB recognized that it could use its strength to play a crucial role in challenging traditional practices, predicated on building trust within the agricultural community regarding newer, different techniques for irrigation. Fundamentally, NCB is a local "capacity building" initiative, aimed at supporting the most effective use, and future sustainability, of investments in irrigation water system within the Gunnison Basin.

Although the NCB vision is made up of many disparate elements, over the years, the group has evolved and is characterized as:

- A producer-led advisory group
- seeking stability, security and protection from water shortages
- driven by site-specific research, analysis and evaluation
- funded by diverse cooperative sources
- focused on understanding water use as it related to niche- and/or cash-crop markets
- interested in improving water efficiency to improve crop quality for use as a market driver

No Chico Brush "Grand Design"

The NCB Partnership was founded upon the premise that increasing the efficiency of agricultural water use is central to achieving sustainability for irrigated agriculture in the Lower Gunnison River Basin. This premise is integral to the "Grand Design" idea envisioned by the NCB Partnership. This "Grand Design" endeavors to comprehensively optimize the water diversion, collection, storage, conveyance, and distribution systems from the source, to the point of application and use, enhanced by irrigation technology that includes innovative infrastructure, measurement, control and communication (e.g., pressurized pipelines, SCADA, telemetry).

The No Chico Brush 'philosophy' is that efficiency improvements are overlooked, important alternatives to traditional approaches that have relied upon the historical "buy and dry" variety of water transfers that results in the removal of water from historically irrigated lands. No Chico Brush places a high priority on increased efficiency in agricultural water use, as a preferred alternative to fallowing programs locally called "lease and cease" or "brown and down" actions.

As part of the development and implementation of a comprehensive, systematic approach to address the issues associated with water availability, demand management, and associated water quality issues, No Chico Brush began applying the "Grand Design" in the Lower Gunnison Basin, focusing on the Uncompahgre and North Fork Valleys, driven by the simple principle of making the 'best use' of water, as possible. In general, the group supports common-sense system improvements that include canal lining, piping, near farm regulated water storage and delivery systems that move away from an 'always on' towards an 'on-demand' system. Such optimization endeavors would include multi-beneficial on- and off-farm innovations and improvements that enable soil-health, reduced deep percolation and runoff that limit contaminant loading, wildlife habitat improvements and even micro-hydroelectric production.

The Grand Design, when implemented, would be a cost-effective method of addressing agricultural water shortages by taking advantage of "system wide conservation" (i.e., optimal timing, diversion on demand, etc.) while also allowing more flexibility under drought conditions. Such flexibility enables: 1) sharing of positive benefits of greater efficiency in the consumptive agricultural sector with the growing non-consumptive (e.g., recreation and environmental) sector; 2) improving water quality by reducing salt and selenium loading from increasing efficient agricultural practices (e.g., sprinklers and drip); 3) conservation of soil by minimizing erosion by reducing less efficient agricultural practices (e.g., flood-furrow); 4) enabling the introduction of soil health improvement practices to increase water holding capacity (e.g., minimum till practices that utilize cover cropping after sweet corn); 5) increasing productivity and profitability to enable growers to reduce the net number of irrigated acres.

The initial focus of NCB was to undertake a series of evaluation projects aimed at building advisory and technical capacity to support greater efficiency in the use of irrigation water. Contrasted with traditional *research*, the purpose of *evaluation* in the agricultural sector is to examine the adequacy of project logic, situational constraints, implementation deficiencies and responses, and overall operational effectiveness. With these goals in mind, NCB wanted to understand the impacts of irrigation water practices and application quantities to crop production and forage yields.

As the research project evolved, the NCB Partnership prioritized the need to evaluate the impacts of improving irrigation practices upon crop quality, in addition to yield, focusing on sweet corn. This reflected the evolving prioritization, motivation and incentives that farmers consider when investing in irrigation technology.

Conclusions and Findings

The results of the NCB-sponsored research project resulted in important locally-specific information and perspective on the potential for irrigation efficiency to address agricultural water resource issues in the Gunnison Basin.

Observations and direct survey results from project participants indicate that 1.) *motivation, 2.) understanding and 3.) developing confidence* were key drivers in the behavioral dynamics and capacity building and the potential adoption of new agricultural practices.

These behavioral drivers combined with analytical results related to quantity and quality of crop yields in comparison to water usage led to the evolution and progression of the project and primary findings over the 5-year study period.

The primary findings include:

- Significant system net benefits (such as increased yields, higher quality agricultural production, decreased labor, decreased input costs leading to increased profitability) can result from increased efficiency in agricultural water use; *potentially motivating participation;* (see Phase I results)

- Potential per acre increases in consumptive use (CU) associated with higher agricultural production due to better agricultural water use efficiency could be offset if better productivity and yields enable producer to a decrease the number of irrigated acres further reducing input costs, leading to higher net profits and sustainability and *potentially motivating participation*; (see enterprise budgets)

- Quality-based agricultural production improvements are an underappreciated *motivating factor* for water efficiency practices, this project found that crop quality and quantity can be improved through increased water efficiency as evidenced by the sweet corn trials; (see Phase II results)

- Implementation and use of moisture monitoring and telemetry technology is important to *increasing understanding* regarding soil mechanics and associated factors related to ’cause and effect’ that can lead to higher adoption rates of water efficiency techniques; (see Phase I)

- Use of meteorological data provided by CoAgMet stations (supported as part of the project) is important to *increasing understanding* regarding climatic drivers that can lead to higher adoption rates of water efficiency techniques; (see Phase I)

- Moisture monitoring technology is essential to water efficiency, however, despite industry-promoted advantages of irrigation efficiency, these approaches are not “plug and play” and require specialized knowledge and a broad network of support (i.e. sensor calibration issues, tech support, pivot removal example) to *build the confidence* needed to be successful; (see Phase I results)

- Agricultural productivity is not adversely impacted by decreased water diversion and/or delivery reductions when operations are informed by moisture monitoring data and locally-derived crop-water demands, industry incentives for diversion reduction, thus *increasing confidence* in water efficiency; (see Phase II results)

- Optimal management could result in approximately 10% reduction in diversions with an *increase* in crop quality (estimated based upon one less irrigation on sweet corn - Phase 2). thus *increasing confidence* in water efficiency techniques. (see Phase II results)

Recommendations

The success and/or failure of agricultural water efficiency research and implementation efforts is strongly influenced by identifying and engaging with a **motivated** sponsor (group) that has a good **understanding** of the known issues and exhibits the willingness and **confidence** to address challenges and uncertainties associated with unknown issues. In other words, going forward, a clearly defined vision is needed to provide motivation (e.g., avoiding water shortages and increasing profitability) for educated producers to confidently engage in efficient water use practices. Such a guided process should form a unified framework to drive water efficiency activities.

Without clear underlying **motivation** driving participation, research and implementation efforts can be subject to undesirable program changes and associated inefficiencies and even unmet expectations. For example, some producers were motivated by drought conditions and the fear of administrative curtailments, while others had envisioned other future scenarios. Thus, a local 'champion' with a clearly elucidated unifying motivation and single, unified vision is essential.

Such a unifying vision more easily leads to the building of a common **understanding** of the solution(s) supported by site-specific research and evaluation. In turn, the analysis and scientific evaluation of research results (e.g., water use and crop quality parameters) and brings the desired **confidence** to the producer reinforcing their **motivation** to participate.

Important Summary Points

- Successful programs require unified motivation
- Producer-driven pathway to newer management and technical tools need to have broad understanding and "buy-in," and acceptance
- Technical evaluation and guided research needed to support behavioral and technical changes
- Guided involvement and scientific research is needed to inform and to inspire confidence
- Independent project data that support scientific conclusions help inspire sufficient confidence to support broadscale adoption and provide answers to deal with doubters and skeptics
- Niche-market agriculture focused on profitable cash crops can support and lead transition to adoption of new technologies in the face of technical challenges
- Incentivization (i.e., funding) for continued and expanded participation is needed
- A local champion (e.g., NCB EC along with water districts such as UVWUA and Conservation Districts is needed for organizational and funding support and to ensure broad adoption

- Conservation technology and water efficiency should play an important potential in “demand management” and potential ATMs.

Implications for Future ATM Projects and Related Colorado Water Plan Activities

Although CU may increase under water efficiency projects, such projects can nevertheless be consistent with CWCB-funded ATM Projects and related Colorado Water Plan Activities that are designed to address current and projected water shortages. In fact, there is an important role that WUE can and should play in Colorado’s water future

Better management (drought response) and preparation for long-term water shortages by employing improved infrastructure, with long-term, well planned technological fixes are important tools to secure water availability, despite the known undesired effect of increased CU and reduced return flows. Although this project was not focused upon how much water could be physically saved, this project was a good fit for ATM funding, as it was an investigation designed to help define the role that water efficiency can and should play in addressing water supply issues in time and space.

As such, the NCB Partnership would advise the CWCB and GBRT to continue supporting funding efforts to build upon the project successes to date. Specifically, the following actions are recommended:

- *Support water efficiency as a multi-purpose BMP*

Additional agricultural water use efficiency research is needed to establish site-specific best management practices to meet multiple objectives and benefits for maximizing productivity with minimal, or optimal, water use while reducing seepage that leads to salinity and selenium loading.

Irrigation improvements is an often-overlooked technique to increase sustainability of irrigated ag in western Colorado and specifically to address the Gunnison Basin predicament. Outgrowth of project findings can and should provide additional guidance for implementation future ATMs and CWP / GBIP projects, and to address future objectives and to reduce uncertainties associated with water availability.

- *Review and create funding tools for water efficiency*

The use of CWCB funding should be prioritized to promote additional investment into WUE and related applied research regarding water use. Such funding could then be used as a tool to leverage competitive matching funds to create practical and sustainable agricultural business practices along with local economic development agencies (e.g., DCED. Region 10, etc.). with a focus on water management. This could directly support agricultural water efficiency practices and quality-driven incentives and even low water use alternative crops. Additionally, these approaches could be combined with and expand impact investment strategies being investigated (e.g., Montezuma County, Colorado)

- *Implement Projects Using Dedicated Water Efficiency Program Manager(s)*

The need for local expertise to support farmers working on agricultural efficiency was observed and documented in the NCB. In this project, support and directed assistance was provided by CSU. Without this support, the project gains could not have been made. For example, in the absence of such direct technical assistance, it was observed that infrastructure improvements (I.e. sprinklers) were actually removed in favor of less efficient practices (gated pipe).

It is recommended that efficiency gains could be protected and expanded with the use of a dedicated water efficiency manager. Such a position could be modeled after the Northern Colorado Water

Conservancy District (or other WCDs) that have paid program managers to augment NRCS and local conservation specialists, who are typically over-subscribed.

These positions would focus on efficient use of water resources through education, collaboration, and leadership. There is tremendous progress in the efficiency industry and society is accepting the importance of water scarcity, use, management and respect. By supporting projects between public, private, and non-profit organizations, the water efficiency program manager supports reduced water consumption, improved performance, and reduced costs using new methods, products, and ideas.

Overall, it was observed that conservation associated with water efficiency involves the confluence of social, scientific and economic factors and these complex and overlapping issues are best addressed by a dedicated water efficiency manager that can assist agricultural producers.

Research for Policy Development and Decision Support

Going forward, additional research support is needed to assist producers to be competitive in the marketplace. Quality-driven parameters are powerful incentives for participating in water efficiency practices and associated conservation practices.

In the future ATM funding may be applicable to support potential, market-driven crop switching to lower water use crops (from perennial to annual crops), niche markets and possibly to support the transition to organic crops, if deemed more profitable and if consistent with natural resource conservation goals (soil health, climate action, etc,).

Lastly, ATM funding might be appropriate to support the monitoring and verification of conserved consumptive use from water conservation irrigation practices and / or niche and alternative crops.

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Section 1

Introduction

1.1 Background and Justification

Based on Colorado State Demographer projections used in SWSI 2010 and the Colorado Water Plan 2015, the population of the Gunnison Basin may double by 2050. With this increased demand, the Colorado Water Plan and associated Gunnison Basin Implementation Plan (GBIP) has projected an agricultural gap between available water supply and agricultural water or full crop demands of 116,000 AF/year (Colorado, 2015). This is on top of existing significant 'shortages' in the ability to meet non-consumptive needs including instream flows for species of special concern and threatened and endangered fish in the Gunnison River within the context of regional supplies and demands as a whole.

The intent of this project, as stated in the original CWCB ATM and WSRA proposals, was to highlight irrigation efficiency as part of the strategy to address the agricultural water gap in the Gunnison Basin. The project participants collaborated to conduct irrigation-related research and disseminate information in the Gunnison Basin. The project also examined the impact that changing on-farm approaches to irrigation will have on important parameters, such as yield, profitability, water management and water quality, that concern farmers and watershed stakeholders. A high priority was placed on conducting evaluations of existing on-farm irrigation improvements to identify barriers to adoption of these newer methods. The need continues to exist for these kinds of farmer-led efforts to help guide and implement efficiency projects. These efforts increase knowledge about agricultural demands and what happens to water on the farm, so that water managers and farmers can make more informed decisions about water and crop management.

1.2 The No Chico Brush Partnership

The No Chico Brush (NCB) Partnership considers the water supply and demand imbalances in the Gunnison and Colorado River Basins to be a severe problem with no easy solutions. Downstream impacts, competition for limited water supplies and associated legal and political threats, exacerbate the challenges. Inaction is not an option for NCB members.

Sidebar: *The No Chico Brush group takes its name from the Chico Brush or Greasewood (Sarcobatus vermiculatus) that is emblematic of landscapes that are deprived of irrigation and farming. The NCB Partnership regularly notes that without sustained farming and irrigation, this plant, as a symbol of non-irrigation, would become more prevalent in the area of the Lower Gunnison. Specifically, the name, No Chico Brush, describes their theme preventing greasewood from overtaking fields that might be subject to fallowing due to water shortages brought about by supply/demand imbalances.*

Without implementing creative water management strategies to improve regional water availability, agricultural land in the Gunnison Basin would at the very least experience ever-increasing strains on water resources and at the worst, become impossibly difficult to farm in its current manner. Given the obvious links between land use and water resources, the NCB Partnership evolved out of the Soil Health Initiative, an ongoing project directed at assisting farmers with implementing practices that improve soil health, profitability, and sustainability of farming in order to address the growing water availability and water quality concerns in the Gunnison and Colorado River Basins. The partnership was further developed in 2013, after the United States Bureau of Reclamation (USBR) published the Colorado River Water Supply and Demand Study (USBR, 2012) indicating that diminishing water supplies were projected not to be sufficient to meet growing demands.

By using funding availed through CWCB and other partnerships, NCB executed a *capacity building initiative* at the local producer level, aimed at supporting the most effective use and future sustainability of investments in irrigation water supplies for the Gunnison Basin. Active farmer participation and farmer-to-farmer outreach was a critical component of this initiative, and will be necessary for future efforts promoted by CWCB and other agencies entrusted with addressing complex water resource problems. Under the NCB Partnership, local farmer leaders have successfully worked with interested parties including Trout Unlimited (TU), The Nature Conservancy (TNC), Uncompahgre Valley Water Users Association (UVWUA), Colorado River District (CRD), Delta Montrose Electric Association (DMEA), Montrose and Delta County Commissioners, local business leaders and lending institutions to envision solutions that give dual priorities to sustainable agriculture and efficient water management. The funding portfolio employed by the NCB Partnership was able to leverage CWCB funds from the Water Supply Reserve Account (Now "Fund") from the Gunnison Basin Roundtable and Alternative Transfer Method Funds to acquire significant cost share contributions from local farmers, TNC, TU, CRD, Upper Gunnison River Water Conservancy District (UGRWCD) and Colorado State University. The array of direct and in-kind support sources reflected the vast interest in supporting this project.

Aside from its important local role, the NCB Partnership also advocated for the designation of the Colorado River Basin as a Critical Conservation Area (CCA) under the NRCS Regional Conservation Partnership Program (RCPP). This successful effort helped direct and acquire cost sharing funds for the Lower Gunnison Project (LGP).

Side bar: *The Lower Gunnison Project (LGP) is a separate cooperative effort, supported in large part by NCB, that got its start after 2014 when a larger partnership used the CCA designation to obtain funding from the USDA-NRCS under the Regional Conservation Partnership Program (RCPP), part of the 2014 Farm Bill. The LGP has helped install numerous WUE projects and it continues today with broad support.*

Formally entitled "Modernizing Agricultural Water Management in the Lower Gunnison River Basin: A Cooperative Approach to Increased Water Efficiency and Water Quality Improvement ("Lower Gunnison Project"), the LGP sought to further the 'Grand Design' envisioned by the NCB Partnership by expanding irrigation efficiency opportunities by integrating on- and off-farm activities and to meet multiple natural resource objectives.

In a sense the LGP expands the grand vision for the improvement of agricultural water collection, management, deliveries and application and in the Lower Gunnison Basin including the Uncompahgre and North Fork Valleys, driven by the simple idea of making the best use of water as possible. The NCB Partnership actively supports the push for improvements to irrigation water systems, including common-sense solutions like canal lining, piping, on-farm storage, and system optimizations as well as more multi-beneficial projects that include hydroelectric production that could help pressurize near-farm laterals and on-farm sprinklers and related irrigation efficiency projects.

Although somewhat beyond the original scope of the NCB Partnership, the following goals and objectives of the LGP are supported by the NCB Partnership: 1) increasing water availability via the implementation of irrigation improvement projects (i.e., off-farm irrigation delivery improvements and integrated on-farm irrigation application improvements, 2) increasing water quality by decreasing deep percolation into and through saline and selenium-rich soils, 3) encouraging and implementing on-farm soil health practices to demonstrate the value of such practices that beneficially impact water use via increased water holding capacity and ultimately lead to increased productivity, and 4) helping aquatic habitat improvement by decreasing selenium (and salinity) loading to occupied critical habitat.

Although the evolution of the NCB concept of a "Grand Design" and project development was separate, it was essentially coincident with the development of the Gunnison Basin Implementation Plan under the umbrella of the Colorado Water plan that was finalized in 2017, NCB's unique approach stands apart from the traditional implementation projects that are primarily devoted to addressing local water supply/demand gaps. Rather the NCB approach is geared towards addressing multiple objectives on a sub-regional basis.

Instead of addressing single project locations and issues, the NCB philosophy takes a more unified, comprehensive approach to integrating more of the 'supply-chain' of issues that affect irrigated agriculture in the LGB. For example, NCB has studied how different irrigation practices can produce different results, not only with respect to implementing highly efficient irrigation technologies such as drip tape and sprinklers but to understand the impacts to crop yield and quality, resulting impacts to return flow amount and quality as well as to soil health and regional environmental impacts.

In addition to benefitting individual producers, NCB partners recognize and encourage irrigation efficiency practices can significantly benefit the larger system, whether as part of a private ditch company, a Water Conservancy District (WCD) or a Water User Association (WUA). This is especially true for the systems that have access to supplemental storage water (i.e., Bostwick Park WCD, Crawford WCD, the North Fork WCD and the Uncompahgre Valley WUA), such that reduced diversions can stay in storage longer, thereby extending the irrigation season or even being carried over from one year to the next.

As the percentage of irrigation infrastructure is improved using technology across watersheds, regions and/or districts, the benefits are multiplied and extend to other, 'non participants' within the system via "system conservation." System conservation due to comprehensive improvements from the point of collection at the water source to the point of use, minimizes water loss, and maximizes efficiency. Water supplies last longer and are more effective through better timing that meets crop demands in time and space. System conservation thereby can further protect regional agriculture by giving more resilience and flexibility under drought or potential water availability restrictions.

Individual irrigation water efficiency projects combined with system improvements increase water user flexibility by enabling irrigators to access options and alternatives to traditional operations without fear of losing water supplies and/or productivity. In so doing, this enables water users to enroll in and participate in related actions like land rotation, crop switching and soil health improvements. Studies show a direct link (cause and effect) of irrigation efficiency to soil health practices and, in turn, to increased farm productivity, and benefits to water quality and water quantity, especially in the saline shales found in western Colorado.

Staying nimble with its funding and resource availability, the NCB Partnership interests evolved from start to finish. Beginning as primarily a means to oversee field evaluations comparing different irrigation practices, then transitioning to a more focused look at how irrigation practices affect specialty crop quality and yields, the NCB Partnership oversaw a number of local farmer-led projects. It initially undertook a number of evaluation projects aimed at building both advisory and technical capacity, understanding and increasing the use of technology in order to support greater irrigation water efficiency. As the NCB Partnership matured, it identified a need to build capacity around promoting crop quality as an incentive to encourage efficient water use. This report summarizes the evaluation, demonstration and research associated with what became two distinct project phases.

1.3 Project Funding and Budget

The NCB steering team actively pursued various grant funding sources in support of this research and educational project. Two primary sources of funding were acquired with the help of the Colorado River Water Conservation District (Colorado River District or CRD) which served as the grant sponsor and fiscal agent. In 2014, Water Supply Reserve Account (WSRA) grant was approved by the Colorado Water Conservation Board (CWCB) and supported by the Gunnison Basin Round Table (GBRT) for $35,000; subsequently, the NCB partners acquired the larger Agricultural Transfer Methods (ATM) grant via the CWCB for $173,080. The contracting phase of the project (with the CWCB) for the two primary large grants was finalized in the fall of 2014.

During the grant review, approval and contracting period, NCB reached out to partners for financial assistance to meet cost sharing requirements and to provide seed funding to initiate filed work in 2014 and to finalize the experimental design. Support was found from Colorado Trout Unlimited (CTU), the Nature Conservancy (TNC), and the Selenium Task Force (STF) (via Species Conservation Trust Funds (SCTF) administered by the CWCB. The combination of sources resulted in a substantial over-match of more than 2:1.

The CTU partners allocated $15,000 to the beginning of the project for research site recruitment, equipment and installation assistance, and TNC funded numerous outreach meetings as part of project formulation and early implementation in 2014-2015 and addition GunnisonRiverBasin.org website support ($10,000). The Upper Gunnison River Water Conservancy District also contributed $5,000 towards additional evaluations in the area around Gunnison Colorado. Colorado State University provided substantial in-kind contributions from project formulation through design, management, analysis to project completion. Not all of these contributions were quantified and not all reflected in the budget summary shown in Table 1.3.1.

The following funding table summarizes tasks, and the related distribution of the awarded and contributed funds at the end of project.

Table 1.3.1: No Chico Brush Summary Funding Table (Final Expenses through 07/31/20)

Task	Description	ATM Budget	WSRA Budget	Cash Expenditures	Match Contribution Pledged (cash & in-kind)	Match Contribution Documented	Total Project Expenditures
1	Project Design & Engineering	$ 42,443.85	$ -	$ 2,962.50	$ 1,000.00	$ 1,620.00	$ 4,582.50
2	Instrumentation	$ 47,005.15	$ 10,000.00	$ 93,180.09	$ 12,000.00	$ 43,000.00	$ 136,180.09
3	Project Management	$ 10,080.00	$ 7,252.75	$ 27,841.99	$ 40,000.00	$ 55,280.12	$ 83,122.11
4	Field Assistants/Interns	$ 4,354.00	$ 6,500.00	$ 62,023.60	$ 7,000.00	$ -	$ 62,023.60
5	Implementation: On-farm	$ 6,600.00	$ -	$ 511.26	$ -	$ 13,470.00	$ 13,981.26
6	Project Data Analysis	$ 3,850.00	$ 5,697.25	$ -	$ 12,000.00	$ 12,000.00	$ 12,000.00
7	Outreach	$ 33,853.00	$ 4,500.00	$ 13,159.15	$ 3,000.00	$ 22,772.00	$ 35,931.15
8	Project Reporting	$ 19,853.00	$ -	$ 2,371.05	$ -	$ 4,297.40	$ 6,668.45
9	CRWCD Admin Fee (3%)	$ 5,041.17	$ 1,050.00	$ 6,030.53	$ -	$ -	$ 6,030.53
	Totals:	**$ 173,080.17**	**$ 35,000.00**	**$ 208,080.17**	**$ 75,000.00**	**$ 152,439.52**	**$ 360,519.69**

Section 2

NCB Phase I: Irrigation Evaluations

2.1 Scope and Objectives

The vision of the NCB Partnership is that off-farm, near-farm and on-farm efficiency projects should be included in regional strategies to address current and future water shortages. Important to advancing this vision, is the need to examine the "hurdles that may exist in implementing projects that make the best use of water possible," as stated in the CWCB ATM Proposal for this project. The hurdles facing the Lower Gunnison basin are similar to those throughout Upper Colorado Region (USDA Region 14), with slow transition to efficient irrigation. Efficient irrigation methods have been adopted much more gradually throughout these areas as compared with the 17 western States, which have seen an approximate 50% decrease in the use of gravity methods (Schaible and Aillery, 2012).

The USDA Farm and Ranch Irrigation Survey (FRIS) estimates that gravity irrigation methods, which include gated pipe, open ditches with siphon tubes and 'wild' flood methods, are still used on 73% of irrigated acreage in the Upper Colorado Region, of which a majority is comprised by basins that make up the western part of Colorado (USDA, 2017). By comparison, these methods are used on only 45% of irrigated acreage in the entire state of Colorado, indicating that the majority of higher efficiency irrigation is located in the eastern part of the state. Furthermore, the amount of land irrigated in Colorado by gravity methods dropped from 65% to 45% between 1984 and 2018, despite a decrease in irrigated acreage, compared with a less dramatic drop from 84% to 73% for the same period in the Upper Colorado Region, which actually saw a small increase in acreage under irrigation (Table 2.1.1*; ibid*.).

Table 2.1.1: Summary of Gravity Irrigation Methods - USDA Farm and Ranch Irrigation Survey

	All Colorado			**Upper Colorado Region (not including Eastern Colo)**		
	All Acres	**Gravity**		**All Acres**	**Gravity**	
2018	2458120	1098563	45%	1472320	1075608	73%
2013	2309178	1196805	52%	1321937	1035080	78%
2008	2865840	1547072	54%	1359888	1036243	76%
2003	2562329	1315863	51%	1366203	1035866	76%
1998	2942230	1663571	57%	1114172	826236	74%
1993	2998888	1867293	62%	1175863	1022393	87%
1988	3271868	2316841	71%	1282324	1064877	83%
1984	3209754	2082242	65%	1323204	1117100	84%

The FRIS also reports on the methods that irrigators use for making management decisions (Table 2.1.2). Soil moisture monitoring tools, which were evaluated by the NCB Partnership, have experienced a decline in usage versus more traditional methods, such as crop conditions or the 'feel of the soil' (i.e., observed texture and characteristics). In fact, the number of farms that report using any method of deciding *when* to irrigate has steadily increased in both Colorado and the Upper Colorado Basin, but the use of soil moisture sensing devices has remained consistently low. Arizona, however, where farming conditions and methodologies can be similar to Colorado, reports a relatively consistent in the use of soil moisture sensors, despite a decline in overall farms reporting. This is shown in the Table 2.1.2.

Table 2.1.2: Soil Moisture Monitoring Methods Used in Decision Making for Irrigation

Calendar Year	**Number of farms reporting**		**Percent**	**Number of farms reporting**		**Percent**	**Number of farms reporting**		**Percent**
	Colorado			*Arizona*			*Upper Colorado Region*		
	Any Type Moisture Monitor	*Soil Sensor*	*Soil Sensor %*	*Any Type Moisture Monitor*	*Soil Sensor*	*Soil Sensor %*	*Any Type Moisture Monitor*	*Soil Sensor*	*Soil Sensor %*
2018	14529	577	4%	3054	211	7%	13188	218	2%
2013	12501	673	5%	4380	174	4%	10352	498	5%
2008	12778	335	3%	2997	68	2%	10771	45	0%
2003	11567	480	4%	2777	100	4%	9068	111	1%
1998	11846	532	4%	2637	223	8%	6455	83	1%
1993	12256	921	8%	3043	255	8%	7580	315	4%
1988	12649	495	4%	3580	230	6%	7218	140	2%
1984	13443	697	5%	3420	241	7%	8130	222	3%

The overall trend represented by persistent use of gravity methods for irrigation, accompanied by lower adoption rates of soil moisture sensing in western Colorado underscore the challenges facing water managers and help stress the urgent need to build greater capacity around these BMPs (Phase I). Despite barriers to their adoption, the pressing concerns over persistent drought, competition for agricultural water, legal availability of water, and water quality degradation persuaded the NCB Partnership to also advocate for better irrigation methods in the Lower Gunnison Basin. Believing that these concerns will eventually necessitate optimizing crop yields, economic returns and water management, NCB Phase I focused on comparing irrigation methods in the Lower Gunnison Basin during the 2013-2016 cropping seasons.

Paraphrasing from the CWCB ATM Proposal for this project, the NCB Partnership seeks to address how improved irrigation efficiency can help fill agricultural water supply gaps while providing additional environmental benefits. The approach taken was to collect important data on crop CU, cropping practices and irrigation methods in the Lower Gunnison in order to inform multiple types of alternative transfer methods such as water banking, interruptible water supply agreements and others. While this project did not have a direct intent of transferring agricultural water, it did look at how efficiency improvements, combined with new management strategies, can address local water supply challenges and avoid the need for costly new storage projects or undesirable “buy and dry” actions on otherwise productive agricultural lands.

Definition of efficiency improvements

Since “efficiency improvements” play such a central role in the NCB Partnership vision, clarification of this term is warranted in order to understand its value as a metric of comparison. The concept of efficiency in irrigation is defined differently, and unfortunately without much consistency (Burt et al., 1997; Perry, 2007).

The terms that apply to this project are:

1.) irrigation efficiency (IE), 2.) irrigation water use efficiency (IWUE) and 3.) water use efficiency (WUE). These terms represent the water effectively consumed by the plants (IE), dollar value added in monetary profit (IWUE), and biomass produced (WUE), respectively, per volume of water withdrawn or applied.

The NCB Partnership vison is supported at multiple scales, because off-farm, near-farm and on-farm efficiency projects are all part of the strategic portfolio of the “Grand Design” idea to address current and future irrigation water shortages. The purpose of NCB Phase I was to support on-farm efficiency projects. Other scales (near- and off-farm) are being investigated by related projects, such as the previously mentioned LGP.

Relative to NCB project and the on-farm efficiency improvements, the questions and associated tasks carried out in this phase were organized around focused categories and two main research phases. First, NCB Phase I included a cluster of field evaluations and technical work. These evaluations were undertaken to collect data on: (1) crop consumptive use (CU), (2) crop impacts, related to (3) irrigation methods.

2.2 Project Design Approaches and Principles

The Phase I data set collected relative to **crop CU** focused on defining site-specific water needs for crops grown in the Lower Gunnison Basin. That is, how much water is applied to these crops (as compared with the actual crop demands throughout the growing season) and how much water do different irrigation methods (e.g., furrow, sprinkler, drip and large impact-head or big gun sprinklers systems) use for similar crop types.

The Phase II data set, discussed in the next Chapter, focused on examining on **cropping impacts** and the effect that changing on-farm approaches to irrigation have crop quality (IWUE) and on yield or WUE. To a lesser extent the NCB research also investigated irrigation method impacts to water quality, a concern to farmers and watershed stakeholders, along with other indirect benefits that accrue from irrigation efficient practices.

The Phase I data set on **irrigation methods** focused on understanding the application efficiency of these different irrigation systems, estimating the amount of water that may be saved by converting on-farm irrigation from open furrow or flood irrigation methods to systemized irrigation with advance irrigation scheduling, as well as understanding how much water returns to the system from the farm as either surface run-off or deep percolation and further understanding the quality of water (e.g., salinity, selenium, nutrients and sediment concentrations and loads) returning to the surface water or river system.

Second, the lessons learned in the NCB Phase I field evaluations were used for building capacity, both advisory and technical, to support projects and methods to improve IE, IWUE and WUE. Capacity-building aimed at understanding how on-farm data can help farmers optimize water use and discerning what types of incentives need to take place to adopt irrigation efficiency methods.

Finally, the field evaluations and internal capacity-building supported an external outreach component for disseminating information on the pros and cons of increased agricultural irrigation efficiency related to advanced irrigation water management. The outreach effort focused on interacting with water users and water managers, synthesizing feedback and findings of the project, and presenting at outreach events in the region.

The core design approach for NCB Phase I was to use paired fields that would allow for “side-by-side" data collection and comparisons of the different irrigation methods. Not all fields were actually contiguous, but selections were made to assure that soil and weather variables were reasonably consistent. The high priority was placed on conducting field evaluations was intended to identify barriers that real farmers face when considering newer irrigation methods. While most sites were set up as *multi-year paired evaluations*, the interests of the NCB Partnership led to some sites being used for *multi-year evaluations of a single field* (crops changed on this field in subsequent years) and/or for *pilot technology testing*.

Farmers who had previously adopted efficient irrigation systems were recruited as hosts of the evaluation fields. The process envisioned by NCB was to evaluate these systems against traditional furrow irrigation, while also highlighting how other on-farm technology, such as soil moisture sensors, remote monitoring and telemetry might be used to improve yields and reduce impacts of shortages.

The diffusion of innovation framework (Rogers, 1995; Rogers, 2003) served as the basis of the irrigation evaluations. This framework identifies five characteristics that primarily influence adoption rates of new ideas and technologies: (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5), observability. Pertaining to efficient irrigation, these characteristics explain why the adoption of new technology has been slow.

Potential users will not adopt innovations that do not offer a *relative advantage* over traditional approaches. As one local farmer put it, “There’s nothing cheaper than running water downhill,” suggesting that the new irrigation technologies must lead to clear, unambiguous financial outcomes. A fairly large body of data exists, for instance, on the economic advantages of irrigating various crops (wheat, grain sorghum, alfalfa hay, onions) under driplines versus furrow. Even accounting for up-front capital expenditures, drip irrigation has been shown to increase net operating profits over furrow-irrigated systems (Hawkes, 2000). These gains are made largely due to labor savings, lower pumping expenses and equipment maintenance costs, but some increases in yields are also evident (Rudnick, 2012).

In the context of senior water rights, marginally lower profitability and water delivery infrastructure driven by gravity, the *compatibility* of irrigation innovations is divergent with existing values, past experiences, and needs of Upper Gunnison irrigators. This is consistent with received wisdom that points to human behavior and values as being more relevant than conveniency or even accuracy and reliability when producers consider adopting new irrigation scheduling methods (Shearer and Vomocil, 1981; Howell, 1996). Whether real or perceived, the *complexity* of these systems is often an impediment to the motivation and understanding necessary for broader adoption, especially in regions where technical support is limited. The degree to which irrigators can build confidence though *trialability* is also important, so that innovations can be experimented with on a limited basis. Adopting new and efficient irrigation systems require investments of time, energy and resources, which concerns many farmers who have little margin for experimentation in their budgets. Lastly, *observability* also helps irrigators build confidence in newer irrigation methods, if positive outcomes stemming from implementation are evident.

Given the on-farm setting of NCB Phase I, a combination of evaluation approaches and inductive research principles was used. The purpose of *evaluation* in this context is to examine the adequacy of project logic, situational constraints, implementation deficiencies and responses, and overall operational effectiveness. This approach was necessary, since on-farm settings cannot realistically and reliably implement experimental designs that would have participating farmers alter or randomize their practices under actual farming conditions. Moreover, the NCB Partnership placed greater value on comparing different irrigation approaches as practiced by farmers who were already implementing them and giving farmers a sense of accessibility to the information.

Despite its focus on evaluation, the project was also able to employ principles of *inductive research*, since the sites were set up as “side-by-side” comparisons between traditional and improved irrigation systems actually implemented in the field. This form of research is concerned with the generation of new theories emerging from observed data, in contrast to deductive research, which is aimed at testing hypotheses and theories. Deductive research projects commonly set up at university Agricultural Experiment Stations, for example, begin with a hypothesis and emphasize determining the causality of outcomes. Inductive research projects in the on-farm setting, on the other hand, start with previously researched concepts and seek to examine them from a different perspective, such as that of the farmer rather than the research scientist. Fundamentally, inductive research is a *search for patterns* based on reasoning from specific observations. By trying to understand what all the given data and observations have in common, the researcher tries to organize the information into manageable categories. It is important to note that the researcher is led to conclusions based on what may be a narrow purview of the data, which is why the project should necessarily employ feedback between the participants (farmers) and the researcher.

2.2 Selection and Design of Evaluation Trials – Phase I

In 2014, prior to CWCB contracting, three paired irrigation evaluation sites were established. Each evaluation field utilized site-specific instrumentation, based on the irrigation system being monitored and the overall intent of the evaluation. Briefly described, the initial three field sites included the following:

HN-B (onion). Multi-year paired evaluation site. Comparison of onion yields and water use in furrow versus drip irrigation systems in Delta, CO.

HN-B (corn) and RN. Multi-year paired evaluation site. Comparison of field corn (grain) yields and water use in furrow versus sprinkler (pivot) irrigation systems in Delta, CO.

MK. Multi-year single evaluation site. Baseline monitoring of a field which would be transition from furrow to a “big gun” sprinkler system in 2015. The 2014 crop for this field was spring barley.

In 2015 and 2016, five paired irrigation evaluation sites and two pilot technology sites were operational, these included:

1.) HN-B (onion). Multi-year paired evaluation site. Comparison of onion yields and water use in furrow versus drip irrigation systems in Delta, CO. These fields are coded as HN-B (onion), but were in a different location than 2014, since the operator moved the drip irrigation system. Soil types are described as Gravelly loam, Silty clay loam, Clay loam, and Clay.

In both 2015 and 2016, yellow onions were planted in 4 seed rows (on 34-inch beds). This planting density contrasts with alternate planting densities of 2 seed rows (on 30-inch beds) or 4 seed rows (on 42-inch beds) used by other producers in the area. The choice of planting density is a decision that the operator makes on the basis of equipment configuration (i.e. planter, cultivator, plow).

In 2015, HN-B site there were 12 beds on the furrow field test irrigated with two sticks (30 feet) of 8-inch gated pipe and metered as described in the instrumentation section. There were 227 beds on the drip-irrigated field (34-inch beds x 227 = 643 feet wide). Both fields were 800' long. The drip irrigation system uses a Netafim® totalizing meter that supplies water to a main line, which in turn irrigates through near-surface tape installed only a few inches deep. The tape is installed and disposed of each year. The drip system applies water to a 28-acre field that also has a white onion section adjacent to the yellow onion section.

2.) HN-R and RN. Multi-year paired evaluation site. Comparison of alfalfa yields and water use in furrow versus sprinkler (pivot) irrigation systems in Delta, CO. This comparison was limited in 2015, due to the fact that the RN sprinkler pivot site (originally in corn) was planted to alfalfa in July 2015. Soil types at HN-R are Clay Loam. Soil types at RN are described as Clay Loam and Sandy Clay Loam, with some pockets of rockier areas.

RN is sprinkler-irrigated by a center-pivot that was installed in 2014. According to the pivot installer specifications, the field is 71.5 ac (44.1 acres for the pivot and an assumed 27.4 acres for the arm), but actual observations suggest that the actual irrigated acreage is 69.3 ac. The field was in corn for grain (5654 Dekalb) in 2014. The alfalfa stand was in its first year in 2015, having been planted on July 1, 2015. This site was historically furrow-irrigated using gated pipe until 2014 when an overhead sprinkler-pivot system was installed. The site receives water from the Ironstone Canal. The site is 69.3 ac (28 ha), was irrigated fully in 2016 using an irrigation plan entirely determined by the producer.

3.) HN-R-F field size is 6.4 ac (which the owner calls an even 6.0 acres). There are 101 beds at 30" spacing. HN-R-F is a furrow-irrigated field with siphon tubes (30 x 1.5", 72 x 2.0", 10 x 2.5", 1 x 3.5") with approximately 10" drop out of the concrete lateral. The complete tubing system can deliver approximately 9.6 cfs, though this value is not achievable due to the hydraulic limitation of the concrete lateral capable of supplying no more than 3.5 cfs. The alfalfa stand was in its third year in 2015.

The 2015 alfalfa data is not directly comparable except on a normalized basis, since the sprinkler-irrigated alfalfa field was just planted this year and the first-cutting on this field occurred at the same time as the third-cutting on the furrow irrigated field.

4.) HW. Multi-year paired evaluation site (HW-F and HW-P). Comparison of grass hay pasture yields and water use in furrow versus sprinkler (pivot) irrigation systems in Hotchkiss, CO on established grass fields. This comparison was also limited in 2015, due to the fact that the HW sprinkler pivot site had the pivot installed in 2015. HW-F and HW-P sites are two fairly close locations where one field was converted from furrow-irrigation to a sprinkler system. The other field is still furrow-irrigated. Soils are Loam and Clay Loam.

The sprinkler pivot at HW-P The area under the pivot is 28 ac and utilizes a Fieldnet control system by Lindsay Corporation. The furrow field at HW-F is 5.8 ac and also managed by Houseweart Ranch and is irrigated by gated pipe. The field receives a significant amount of tailwater from other portions of the farm.

5.) MK. Multi-year single evaluation site. Continued monitoring during and after transition from furrow to a "big gun" sprinkler system in Montrose, CO. A cover crop of sorghum sudan-grass, triticale and turnips was planted to this field in 2015 and into 2016 for corn. Soil types on the field vary in accordance with the slope. The upper portion of the field is categorized as Sandy Loam while the downhill portion where more of the clays have historically aggraded is categorized as and Sandy Clay Loams or Clay Loams. The study field size was defined as 10.5 acres, based on the original length of gated pipe used. The field was planted to spring barley (Certified Golden Eye Spring Barley) in 2014 and irrigated by gated pipe. After the installation of the big gun system was complete by July 2015, the owner planted a combination of sorghum sudan grass, triticale and turnips as a cover crop. The field was planted to corn in 2016 on May 22.

6.) TR. Pilot technology evaluation site. Baseline monitoring groundwater table movement in a grass hay pasture field under wild flood irrigation. This evaluation is being done to determine options for greater irrigation efficiency under irrigation systems controlled via swales and tarps.

7.) TK. Pilot technology evaluation site. An automated system (AgSense Field Commander FC2 TL-24) was installed for the operator to demonstrate the value of technology that can start and stop the pivot through a telemetric system accessible via a smart phone. Soil moisture monitoring was also installed to assist the producer in setting the start and stop regimes for the pivot.

The NCB irrigation evaluation sites are mapped in Figure 2.1 in the List of Figures.

Table 2.3.1 provides a summary of NCB Irrigation Evaluation site characteristics.

Table 2.3.1 Summary of NCB Evaluation Sites, type and time period of monitoring.

Field	*Crop*	*Year*	*Plant or Green-up Date*	*Harvest or Cut Date*	*Evaluation Period*
HN-B-F1	yellow onion	2014	Apr 5	Sep 18	monitored irrigation only
HN-B-D	yellow onion	2014	Apr 5	Sep 18	monitored irrigation only
HN-B-F2	corn grain	2014	Apr 25	Oct 15	monitored irrigation only
RN	corn grain	2014	May 3	Oct 18	monitored irrigation only
MK	spring barley	2014	Apr 26	Jul 25	monitored irrigation only
HN-B-F1	yellow onion	2015	Apr 7	Sep 20	Apr 7 – Sep 18
HN-B-D	yellow onion	2015	Apr 7	Sep 20	Apr 7 – Sep 18
HN-R-F	alfalfa	2015	Apr 1	Jun 1, Jul 1, Sep 11	May 13 – Sep 30
RN	alfalfa	2015	Jul 1	Sep 14	Jul 15 – Sep 30
HW-F	grass hay	2015	Apr 1	grazing	Apr 14 – Sep 30
HW-P	grass hay	2015	Apr 1	grazing	Jul 2[†] – Sep 30
MK	cover crop	2015	July 1	not harvested	Jul 15 – Sep 30
HN-B-F1	yellow onion	2016	Apr 9	Sep 20	Apr 13 – Sep 15
HN-B-D	yellow onion	2016	Apr 9	Sep 20	Apr 13 – Sep 15
HN-R-F	corn grain	2016	Apr 25	Oct 15	May 20 – Oct 4
HN-R-L	corn grain	2016	Apr 25	Oct 15	May 25 – Oct 4
HW-F	grass hay	2016	Apr 1	grazing	Apr 1 – Sep 30
HW-P	grass hay	2016	Apr 1	grazing	Apr 1 – Sep 30
RN	alfalfa	2016	Apr 1	Jun 3, Jul 12, Aug 16	Apr 1 – Sep 30
MK	corn silage	2016	May 7	Sep 15	Jun 4 – Sep 15

[†] Reliable data from pivot flow meter was only available from July 2 onward.

2.3 Methods and Materials

2.3.1 Irrigation Evaluations

The irrigation evaluation sites served the purpose of collecting data on crop CU and irrigation methods. Both of these variables require instrumentation that allows for calculation of a soil water balance to estimate evapotranspiration, which represents crop CU. Measurement of inflows to the irrigated fields is necessary for calculating the various representations of efficiency in agricultural water use.

Soil Moisture Monitoring. Soil water levels serve a valuable purpose in calculating the soil water balance (SWB). This approach can be used to estimate ET by tracking the soil water deficit in the root zone (Burt, 1999). Watermark sensor manufactured by Irrometer® (Riverside, CA) were used in these evalutions. The Watermark is a modified electrical resistance block composed of two electrodes embedded into a cylindrical granular matrix which is buried in the soil. WatermarkTM sensors are relatively inexpensive, long-lasting and a "maintenance free." Rather than measuring soil moisture directly, the WatermarkTM sensors effectively measures the soil matric potential (ψm) by monitoring water movement through the porous granular matrix when in good contact with the soil. Soil water potential is measured as a function of the change in resistance between the two electrodes. The associated matric potential is then related to soil water content (θ) using soil water characteristic curves, which were developed using the Soil Plant Atmosphere Model (SPAW) developed by the USDA

The SPAW model is available at http://hrsl.ba.ars.usda.gov/SPAW/Index.htm.

Soil tension data was downloaded from the Sensmit cloud “dashboard” and then processed for each individual station. Processing involved completing the raw data files to fix skips by inserting data points based on prior and subsequent data, and based on relationships to other depths. Because the Sensmit system reports every 30 minutes ideally, the raw data was then queried to build 24-hour data files by selecting each daily data point recorded at 9:00 AM. Tension data within each 24-hour period did not vary substantially. For some of the NCB Evaluation Sites, installation of sensors prior to planting and maintaining them after harvesting was not possible, given the constraints of field operations for row crops in particular. Therefore, soil moisture data was collected within the longest possible observational period and estimated for days prior to sensor installation.

Irrigation Inflow. Irrigation water volumes diverted to the HN-B-F and HW (furrow-irrigated) and RN (sprinkler pivot) sites were measured using in-line McCrometer® McPropellerTM flow meters installed inside gated pipe sections that were installed specifically for the irrigation evaluations. Flow meters were installed downstream of manufacturer-recommended straightening vanes to prevent turbulence. Meters were placed upstream of “pressure bumps” to force full-flow conditions and continuity at the meter. These meters were equipped with instantaneous flow rate indicators to totalize flow volumes, after which data was delivered to MadgeTech® data loggers.

The HN-R-F (furrow-irrigated) site was measured using EZ FlowTM ramp flumes (manufactured by Welfelt Fabrication, Delta, CO) installed in the concrete lateral serving the field and equipped with stilling wells and automatic Global® pressure transducer and data loggers. The actual rate of irrigation was calculated using two flumes for measuring upstream inflow and then carriage water, to determine the actual water supplied to siphon tubes. Ramp flumes were fitted with wingwalls on upstream and downstream flanges. The drip irrigation system at HN-B-D (drip irrigated) uses a Netafim® totalizing meter that supplies water to a main line. The HW-P site (sprinkler pivot) was equipped with a preinstalled meter and accessed using FieldNet® software.

Rainfall Precipitation. Precipitation was monitored with Productive Alternatives® direct-read raingages and checked for timing against the daily record from the nearest CoAgMet station (www.coagmet.com).

Groundwater. Upflux and deep percolation of subsurface water movement is difficult to monitor in the field. Nevertheless, instrumentation was installed to assess the potential contribution of capillary rise (upflux) and loss of water to deep percolation. Because a 1-dimensional model was to be applied at the sites, lateral flow of water was not measured. Capillary rise and deep percolation were assessed relative to the dynamic elevation of any groundwater table, which was measured using 1.0” PVC observation wells and Solinst® Level Logger JuniorTM pressure transducers. The transducers installed in the observation wells were corrected for barometric pressure using Solinst® BarologgersTM.

The full system for irrigation evaluation monitoring is depicted in the List of Figure as Figure 2.2

2.3.2 Pilot Technology Evaluations in the Upper Gunnison

In addition to technology evaluations in the primary NCB areas of Uncompahgre and North Fork valleys, conjunction with Colorado Trout Unlimited, the No Chico Brush partnership worked with some willing flood irrigators in the Upper Gunnison River Basin to experiment with some “Pilot Technology” to increase irrigation efficiency and automation techniques while assessing issues and obstacles.

Upper Gunnison. Flood irrigation is the primary method used to irrigate over 70,000 acres in the Upper Gunnison basin. In general, due to the short growing season and the large volume of water needed to irrigate the highly permeable cobble substrate present throughout the valley efficiency improvements like piping ditches and converting to sprinkler are perceived to be undesirable. In addition, such improvements can be cost prohibitive for grass hay producers in this area. Changing historic flood irrigation practices can adversely impact irrigation-supported springs, seeps, wells, and tributary return flows; this is also an important issue when considering potential efficiency improvements. Furthermore, most ditches in the Gunnison deliver surface water and return flows that may be captured and rediverted multiple times and redistributed to hundreds of acres of irrigated meadows. Significantly changing these historic flow patterns can require comprehensive redesigning of irrigation systems.

In the face of these challenges, adapting flood irrigation strategies to improve the effectiveness of each drop of water diverted is essential as producers face decreasing water supply and increasing pressure by competing uses. Irrigation scheduling has proven to be an effective efficiency tool for flood irrigators while still maintaining ground water levels and near historical return flow patterns. At present, lack of available labor and time can delay desired, optimal irrigation set changes. In turn this can reduce water availability to other locations within a ditch system or the watershed. In fact, accurate irrigation scheduling is particularly critical during short water years when sufficient water is not available in time and location for streams and/or ditch systems.

Matching the “set” time to the needs of irrigated hay fields and meadows is difficult in the face of week-to-week variability, depending on climate and soil conditions. Advances in technology can allow water users to monitor these conditions via remote sensing and plan irrigation delivery to match demands with minimal labor and reasonable investment.

In 2017, the UGRWCD began the Upper Gunnison Watershed Assessment to develop solutions to protect all existing used in the face a climate change and future demands. Conveyance, water shortages and irrigation water management were three issues identified with this assessment. The NCB pilot technology project was developed in coordination with the assessment committee to implement and share these examples with agricultural producers in Western Colorado.

In 2018, TU worked with the large-scale ranchers to develop a prototype irrigation check structure that can be set to automatically open at a specified time. Five of these structures were placed in a ditch then programed to open in consecutive order thereby preforming an irrigation “set” automatically over a three-day period. This task will expand the use of the “Trampe prototype” and retrofit five check structures on a ranch in the East River watershed. This field is long and narrow and if sets are not changed 2-4 times a day, grass hay production suffers. The water user currently manually stacks and removes boards at these structures to distribute the water to the field. Automated scheduling will allow water user to effectively irrigate the meadow with estimated 15% less water and the automatic structure will save and estimated 20 hours a week in labor.

This task also included the design and installation of six auto-close gate inserts to fit into new concrete structures on the Trampe Ranch. The concrete structures will be constructed using a standard form that can be replicated. The design allows the irrigator to remove and place the gate inserts and interchange between structures on the ranch. For example, six of the inserts can be placed in a ditch segment, operated, then moved to the next segment when that set is complete. Using the same inserts at multiple locations will allow a water user to upgrade to automation without a large investment to outfit every structure on the property.

A contractor constructed the frame and plate insert with the latch, shocks and timer similar to what was used with the 2018 Trampe prototype. In May of 2019, CTU assisted water users to install similar auto-gate inserts on up to 5 irrigation check structures on the Anders Ranch. Additional construction was to take place to insert the auto-close gate insert for the Trampe Ranch. This frame and plate structures will be like the auto-open but auto-closing will eliminate the need for the gas shock, thereby further reducing the overall cost. Partner CTU coordinated the design and installation of the concrete structures and plate inserts.

North Fork Gunnison. An automated system (AgSense Field Commander FC2 TL-24) was installed for the operator to demonstrate the value of technology that can start and stop the pivot through a telemetric system accessible via a smart phone. Soil moisture monitoring was also installed to assist the producer in setting the start and stop regimes for the pivot.

2.4 Results and Discussion

The vision and objectives of NCB Phase I were executed with varying degrees of success, depending on farmer participation, challenges in actual implementation, local expertise, funding constraints and the related innovations throughout the project. Nevertheless, a large body of valuable data and information was gathered during the NCB Phase I evaluations and inductive research activities.

Crop CU was calculated as a function of the gross irrigation requirement (GIR) or Irrigation Water Requirement (IWR). Satisfying crop evapotranspiration (ET) demand is the primary purpose of the GIR. For this study, GIR was quantified as the measure of total water actually applied to the NCB Evaluation Fields. Irrigators work to supply the net ET requirement while at the same time overcoming inefficiencies in their irrigation system (NRCS, 1997). Furrow irrigators sometimes use 24-hour sets to reduce labor costs, for instance.

Actual crop CU is variously defined. On the upper end of the range is the potential evapotranspiration (PET), which is modeled using weather-based variables and tends to represent an ideal growth rate under well-watered conditions. The Blaney-Criddle equation (Blaney and Criddle, 1962) is still used despite acknowledgement that it demonstrates variable adherence to the actual ET (AET) of reference crops (Sammis et al., 2011). Use of Blaney-Criddle has gradually declined, however, and been replaced by updated models such as the Kimberly-Penman (Wright, 1982), Penman-Monteith FAO-56 (Allen et al., 1998) and ASCE Standardized Reference Evapotranspiration (ASCE-EWRI, 2005) equations.

If yield data is known, crop production functions can also be related to actual ET (AET) rates. Finally, if irrigation water balances are conducted, it is possible to evaluate AET in the field. These balances are dependent upon the accuracy of the sensing equipment and the controllability of the experiment in terms of known field sizes, soil characteristics and rooting depths of crops. Nevertheless, an irrigation water balance may determine trends in moisture changes that can be related to AET.

The GIR of the NCB Evaluation Fields were based on site-specific biophysical factors, including availability and frequency of effective precipitation, soil type and heterogeneity, prevailing wind speeds and humidity, field dimensions and configurations and farmer knowledge of critical plant growth stages. Other offsite considerations that affected irrigation decisions included labor availability and water supply. These factors guide farmer rubrics and historical site knowledge that in turn influence decisions regarding when, and at what rates, to apply water at each NCB Evaluation Field. Ultimately, the GIR is determined by farmers as different events drive the conditions of their cropping seasons. Table 2.4.1 summarizes these results.

Table 2.4.1 Acreage and gross irrigation by furrow, overhead sprinkler, drip and big gun systems for similar crops on NCB Evaluation Fields in the Lower Gunnison.

Field	***Crop***	***Year***	***Field Size (acres)***		***Irrigation Method***	**Application Volume (*ac-in*)**		**Application Rate (inches/acre)**	
HN-B-F1	yellow onion	2014	1.0		furrow	32.1		32.1	
HN-B-D	yellow onion	2014	28.0		drip[1]	547.5		19.6	
HN-B-F2	corn grain	2014	1.6		furrow	63.1		39.4	
RN	corn grain	2014	69.3		sprinkler[2]	1322.8		19.1	
MK	spring barley	2014	10.5		furrow	635.0		60.5	
HN-B-F1	yellow onion	2015	0.6		furrow	43.2		72.0	
HN-B-D	yellow onion	2015	12.8	5	drip[1]	728.7	5	26.0	
HN-R-F	alfalfa	2015	6.4		furrow	453.2		70.8	
RN	alfalfa	2015	69.3		sprinkler[2]	1356.5		19.6	
HW-F	grass hay	2015	5.8		furrow	853.6		147.2	6
HW-P	grass hay	2015	28.0		sprinkler[2]	597.6		21.3	
MK	cover crop[4]	2015	10.5		big gun	141.8		13.5	7
HN-B-F1	yellow onion	2016	1.3		furrow	63.2		48.6	
HN-B-D	yellow onion	2016	3.9		drip[1]	81.1		20.8	
HN-R-F	corn grain	2016	6.4		furrow	916.5		143.2	
HN-R-L	corn grain	2016	67.9		sprinkler[3]	2050.6		30.2	
HW-F	grass hay	2016	5.8		furrow	600.3		103.5	
HW-P	grass hay	2016	28.0		sprinkler[2]	397.6		14.2	
RN	alfalfa	2016	69.3		sprinkler[2]	2064.0		29.8	
MK	corn	2016	10.5		big gun	227.9		21.7	7

1 Drip irrigation system uses shallow buried (1-2 inches) tape with emitters close to the ground surface.

2 Sprinkler systems at HW-F and RN use center pivots with overhead application

3 Sprinkler system at HN-R uses a linear move with overhead application

4 Cover crop system of sorghum sudan grass, triticale and turnips

5 Drip-irrigation system served both yellow onion field (15.2) and a white onion field (12.8) in 2015. The study compared only white onions, however, so the 12.8 ac is reported as the field size for the study. The metered volume, on the other hand, applied to the entire 28 ac field.

6 Field receives tailwater from other fields.

7 Applied volume was deconstructed from recorded irrigation programming

The PET values for the crops studied at the NCB Evaluation Sites were calculated using the "tall crop" alfalfa reference ET0, multiplied by the appropriate crop coefficient. Reference ET0 values were determined by the ASCE Standardized Reference Evapotranspiration equation using CoAgMeT data for nearby stations in Delta, Hotchkiss, Olathe and Montrose. Standard FAO crop coefficients for corn, grass hay, small grains were used. A variable crop coefficient for onion, however, was used to account for the percentage of canopy cover shading the ground during the course of the season, based on the work of Grattan et al. (1998):

One approach to address the question of how much water crops actually need is the crop production function (CPF) approach. The CPF is the relationship between yield and crop CU (Doorenbos and Kassam, 1986). The collection of crop yield data by in-field sampling and producer reports enabled crop production functions to be used as an alternative approach to estimating ET rates at the NCB Evaluation Sites, using yield data collected in the field or supplied by NCB Participants. Estimates of ET using crop production functions are expected to be, but not always, lower than ET predicted on the basis of crop coefficients and ideal reference conditions. Hansen et al., (2008) summarized the results of several studies documenting the relationship between ET and alfalfa yield. Corn grain and corn silage production as a function of ET was reported by Trout and Bausch (2012) for the Central Plains. Smeal et al. (2005) reported on the yield response to ET for several species of pasture grasses. Spring barley crop productions were reported by Kallsen et al. (1982). Ungraded onion yield response to ET has been studied by Al-Jamal et al. (2000), who reported a crop production function and water production function (water applied versus yield) using a subsurface drip irrigation.

Measured crop yield differences and estimated crop CU between furrow, overhead sprinkler, drip and big gun irrigation systems are shown in Table 2.4.2.

Table 2.4.2 Crop CU use represented by potential ET and crop production functions.

Field	*Crop*	*Year*	*Yield*	*Units*	*PET (in)*	*CPF (in)*
HN-B-F1	yellow onion	2014	55,369	lb/ac[1]	30.0	29.5
HN-B-D	yellow onion	2014	65,615	lb/ac[1]	30.0	32.9
HN-B-F2	corn grain	2014	153	bu/ac	25.4	19.0
RN	corn grain	2014	228	bu/ac	25.4	23.0
MK	spring barley	2014	75	bu/ac	20.2	17.3
HN-B-F1	yellow onion	2015	55,762	lb/ac[1]	27.2	29.6
HN-B-D	yellow onion	2015	78,252	lb/ac[1]	27.2	37.1
HN-R-F	alfalfa	2015	4.4	T/ac	39.3	27.8
RN	alfalfa	2015	1.0[†]	T/ac	18.9	7.9
HW-F	grass hay	2015	1.1	T/ac	33.8	21.2
HW-P	grass hay	2015	1.7	T/ac	33.8	24.4
MK	cover crop[*]	2015	---	---	15.7	---
HN-B-F1	yellow onion	2016	84,089	lb/ac[1]	31.4	39.1
HN-B-D	yellow onion	2016	72,879	lb/ac[1]	31.4	35.4
HN-R-F	corn grain	2016	235	bu/ac	25.8	23.0
HN-R-L	corn grain	2016	227	bu/ac	25.8	22.7
HW-F	grass hay	2016	0.96	T/ac	35.4	19.7
HW-P	grass hay	2016	---	---	35.4	---
RN	alfalfa	2016	5.7	T/ac	42.6	33.0
MK	corn silage	2016	26.0	T/ac	23.4	19.0

[1] Ungraded Yield

[†] Alfalfa was seeded in 2015

[‡] Added 1.0 inches to ET rate since the evaluation period did not include April 25-May 20 (for HN-R, 2016) and May 7-June 7 (MK, 2016). The addition of 1.0 inches is a conservative amount and is most likely larger, perhaps by a factor of 2.

Another approach to address the question of how much water crops actually need is to calculate the soil water balance to determine water supply limited consumptive use (WSLCU), which is a term used in the State CU database in Colorado. The WSLCU is a practical baseline for quantifying ET or CU at the field-scale. The WSLCU is an estimation of the water actually used by crops during the growing season, as limited by both legal and physical water availability constraints. The Statewide Water Supply Initiative (CWCB, 2007) contrasts Colorado's water needs for irrigation using the Irrigation Water Requirement (IWR) and the WSLCU, using the difference between these two numbers as an estimate of agricultural water shortage (i.e., the “agricultural water supply gap”).

The recorded measurements for the NCB Evaluation Sites were used to estimate actual ETc by algebraic closure using the simple equation ETc = Peff + Irr + U -SRO – DP – (Dp – Dc) where Dc and Dp are soil moisture deficits for current and previous day. The soil moisture deficit is calculated by subtracting the current moisture level in the root zone from the field capacity of the root zone. Additionally, ETc is crop evapotranspiration, Peff is effective precipitation, Irr is irrigation, U is upflux groundwater contribution (capillary rise), SRO is surface runoff and DP is deep percolation. Limitations to the SWB approach include difficulty in capturing intra-field variability and the reliance on sensors that frequently require gravimetric calibration (Varble and Chávez, 2011). Nevertheless, because the SWB is an in-situ monitoring technique, it is a valuable field method for evaluating irrigation water management and understanding WSLCU.

The U, SRO and DP variables are difficult to estimate in the field. However, if the water table is significantly deeper than the root zone, it can be assumed that U is zero. Also, SRO and DP can be accounted for in a simple way by setting Dc to zero whenever water additions (P and Irr) to the root zone are greater than Dp + ETc. Using these assumptions, the ETc calculation can be simplified to ETc = P + Irr – Dp.

The SWB approach was taken to make only conservative assumptions (i.e., regarding crop rooting depth) that adhered strictly to published scientific literature results and observations. Daily ET rates were developed using a 1-D IWB in a spreadsheet-based model. The procedure undertaken was as follows:

1. Compile soil tension data to represent the moisture conditions in the field
2. Obtain lab analysis to obtain basic soil characteristics (field capacity, wilting point))
3. Develop soil water characteristic curve from published literature and convert soil tension data to soil moisture
4. Choose root depth for given crop based on published literature
5. Remove strong outliers that are evident as a result of rapid shifts in soil moisture due to irrigation and difficult for simple 1-D modeling of IWB to accommodate.

Laboratory analyses were performed for soils at the NCB Evaluation Sites. These analyses are summarized in Table 2.4.3 and provide a useful data set for farmers who wish to adopt irrigation scheduling approaches.

Table 2.4.3 Soil Characteristics at the NCB Evaluation Sites and additional sites for NCB Partners

Site	*Tested*	*Field*	*Field Capacity*	*Wilting Point*	*Available Moisture*	*Textural Class*	*%C*	*%S*
RN[1]	2014	East	17.9 %	8.1 %	9.8 %	Sandy Loam	21	61
RN[1]	2014	East	17.4 %	8.9 %	8.5 %	Sandy Clay Loam	24	52
RN[2]	2016	West	23.1 %	9.3 %	13.9 %	Clay Loam	21	60
HN-B[1]	2014	Furrow	18.1 %	9.6 %	10.6 %	Sandy Clay Loam	21	62
HN-B[1]	2014	Furrow	18.6 %	9.8 %	11.4 %	Sandy Clay Loam	24	58
HN-B[1]	2014	Drip	19.0 %	9.7 %	12.7 %	Clay Loam	38	38
HN-B[1]	2014	Drip	19.2 %	9.9 %	12.3 %	Clay Loam	37	36
MK[1]	2014	West	18.5 %	8.5 %	10.7 %	Sandy Clay Loam	49	32
MK[1]	2014	West	22.0 %	11.3 %	12.0 %	Clay Loam	32	39
MK[1]	2014	East	20.6 %	10.7 %	12.9 %	Sandy Loam	78	14
MK[1]	2014	East	19.3 %	9.7 %	11.4 %	Sandy Loam	68	18
HW-F[2]	2016	Center	31.3 %	14.0 %	17.3 %	Loam	40	20
HR-1[2]	2016	Drip Z1	19.1 %	5.5 %	13.6 %	Sandy Loam	17	63
HR-2[2]	2016	Drip Z2	22.5 %	17.4 %	5.1 %	Sandy Clay Loam	25	50
HR-3[2]	2016	Drip Z3	23.9 %	8.5 %	15.4 %	Clay Loam	28	40
HR-4[2]	2016	Drip Z4	25.0 %	7.8 %	17.2 %	Clay Loam	30	45
HR-5[2]	2016	Drip Z5	24.5 %	8.6 %	15.9 %	Clay Loam	28	44
TK P4-I[2]	2016	Inside	32.5 %	17.6 %	14.9 %	Silty Clay Loam	40	20
TK P4-O[2]	2016	Outside	31.8 %	14.9 %	16.9 %	Silty Clay Loam	30	20
TK P5-I[2]	2016	Inside	34.0 %	19.9 %	14.1 %	Silty Clay	53	7
TK P5-O[2]	2016	Outside	35.2 %	16.7 %	18.5 %	Clay	54	9

[1] Tested at CSU Soils Testing Lab (Ft. Collins, CO)
[2] Tested at Midwest Laboratories (Omaha, NE)

Soil moisture was then divided into “compartments” downward in the root zone from 0-6”, 6”-12”, 12”-18”, 18”-24” and then from 24” to the depth of the root zone. This decision was also necessary because each soil moisture monitoring station could only accommodate 3 sensors which were set at 12”, 24” and at as deep a location that was penetrable by the hand probe used to install them. Moisture data for the 0-6” range was assigned the same value as the 12” range, despite this being an assumption that could represent lower than actual tension. Moisture data for the 18”-24” range was averaged from the 12” and 24” readings. Moisture data in the deepest compartment was assigned the value of the deepest sensor, since crop consumptive generally diminishes in the lowest section of the root zone and was not observed to change as significantly. The only exception to the above configuration was for the onion field, at which sensors were installed at 6”, 12” and 24”. Therefore, at each station, the manufacturer recommendation for the top 2 sensors was used and the lowest sensor was placed at the approximate depth of the root zone to track deep soil moisture.

Development of soil Water characteristic curves was necessary in order to estimate soil moisture (Dp and Dc above). Because WatermarkTM sensors measure matric potential in centibars (Cb), the sensor readings must be calibrated to volumetric water content (%) by using published soil water characteristic curves or developing curves experimentally from gravimetric comparisons. Saxton et al. (1986) and Saxton and Rawls (2006) developed soil water characteristic curves for a wide range of soil textures and incorporated them into the Soil Plant Atmosphere Model (SPAW) developed by the USDA and used in this report. Additional soil water characteristic work was performe by Varble and Chavex (2011),

The SPAW model is available at http://hrsl.ba.ars.usda.gov/SPAW/Index.htm.

Estimating the SWB requires knowledge or assumptions regarding crop rooting depth. Crops extract soil water in varying proportions with depth into the root zone. The majority 70%-80% of crop water uptake occurs in the top half of the rooting depth. However, the concept of the SWB is that a mass-balance is performed for a known depth and thus water extracted should be reflected by the changing water balance, regardless of proportional rates by depth. Rooting depth is affected by factors such as the water application amounts, irrigation scheduling and soil characteristics, the latter of which can be quite heterogeneous for larger fields such as the NCB Evaluation Sites. Although crop rooting density with depth will not be constant, some assurance of modest uniformity may be evident from the uniformity of the stand or crop. Therefore, a single crop rooting depth for each 1-D IWB was selected based on published literature and field observations as summarized in Table 2.4.3 below.

Table 2.4.3 Site-specific soil water characteristic curve values for the NCB Evaluation Sites

Field	***Crop***	***Year***	***Root Depth (in)***	***Soil Water Calibration Method***	***Notes***
HN-B-F1	yellow onion	2015	18	Saxton et al. (1986) – %S 60, %C = 24	
HN-B-D	yellow onion	2015	18	Saxton et al. (1986) – %S 60, %C = 24	
HN-R-F	alfalfa	2015	60	Varble and Chavez (2011)	third year
RN	alfalfa	2015	6, 12, 18, 24[†]	Varble and Chavez (2011)	seeding year
HW-F	grass hay	2015	60	Saxton et al. (1986) – %S 60, %C = 24	
HW-P	grass hay	2015	60	Saxton et al. (1986) – %S 60, %C = 24	
MK	cover crop[*]	2015	36	Varble and Chavez (2011)	establishment
HN-B-F1	yellow onion	2016	18	Saxton et al. (1986) – %S = 40, %C = 20	
HN-B-D	yellow onion	2016	18	Saxton et al. (1986) – %S = 40, %C = 20	
HN-R-F	corn grain	2016	36	Varble and Chavez (2011)	
HN-R-L	corn grain	2016	30	Varble and Chavez (2011)	
HW-F	grass hay	2016	60	Saxton et al. (1986) – %S 60, %C = 24	
HW-P	grass hay	2016	60	Saxton et al. (1986) – %S 60, %C = 24	
RN	alfalfa	2016	48	Varble and Chavez (2011)	second year
MK	corn silage	2016	36	Varble and Chavez (2011)	

Alfalfa is one of the more interesting crops in which to study crop rooting depth. For alfalfa at the RN site, rooting depths were estimated at no more than 60 inches based on published literature and based on field examinations where drilling depths were 82, 77, 62, 40 and 38 inches when installing the observation wells. Drilling depth and consequently plant rooting depth was likely impacted by resistant gravel deposits characteristic of the mesa where the site is located. As noted by Ley et al. (1994), if soil depth is shallow or if a soil layer impedes root or water penetration, this depth becomes the effective rooting depth.

Additionally, the alfalfa stand at the study site had been planted recently (July 2015), so a fully mature and deep root system was not expected. Previously cited research on two-year-old alfalfa plants grown under irrigation in dry upland soil in New Mexico, for instance, had roots 3 to 4 feet deep where 2 inches of water were applied during each irrigation event (Thompson and Barrows, 1920). Lastly, previous research showing that under high frequency irrigation, as practiced by sprinkler systems, crops expected to have 4.0 rooting zones in deep uniform soil are often found to be extracting water only to depths of 18 to 24 inches in the profile (Ley et al., 1994). This is generally due to the diminished need for plants to seek water from deeper zones in the soil profile. Therefore, it is possible that rooting depth was even shallower, but a more thorough physical examination of root depths is needed.

An example of a soil characteristic curve (Figure 3) developed using this method for this project is shown in the Appendix for the RN site

It is noted that the objective of the SWB evaluation was to determine basic trends in ET rates and not to model water movement using a sophisticated model. Therefore, based on the approaches and assumptions described above, the IWB equation for daily ET was simplified as follows, based on the study site conditions and caveats:

ETc = Dc – Dp (when Irr = 0.0, Peff = 0.0, SRO + DP = 0.0, and U = 0.0)

ETc = Peff + Irr – Dp (for Dc < 0.0 when Peff + Irr > exceed soil field capacity)

These calculations were performed in MS Excel using the following conditions.

- The most typical was the outcome in which daily ETc fell within an expected range of ET rates for well-irrigated crops in the study region. All estimations for this outcome were accepted in the summation of monthly ETc.
- The second outcome occurred when ETc rates were greater than zero but less than 0.05 inches per day. Given the lower frequency and higher variability of irrigation at these sites, especially when fields received no irrigation, these lower ETc rates were deemed reasonable and were also accepted.
- The third outcome occurred when IWB-derived daily ETc rates were calculated to be negative. Negative AET values have been noted to manifest occasionally in AET evaluations, due to actual processes, such as condensation, or data quality issues, in assumed precipitation for instance (Wang et al., 2015). Negative AET values were extremely infrequent, and occurred near at large irrigation events, but in order to accommodate them a rolling average of the 3 nearest calculated ET rates was substituted.
- The fourth outcome occurred in the instances when the estimated ETc rates was affected by large changes in Dc - Dp, due short-term processes that could not be captured, such as drainage from the lower root zone only. This outcome was highly infrequent, occurring in approximately 5% of the daily estimates.

Based on the crop production function (CPF) and SWB methods to calculate WSCLU, the IE of the different evaluation sites could be determined, as shown in Table 2.6. This exercise addressed the question of ow much irrigation water can be saved by converting on-farm irrigation from open furrow or flood irrigation methods to more innovative methods. Attainable irrigation efficiencies for graded furrow, sprinkler (with spray heads) and drip irrigation are also reported at 80%, 95%, and 95% (Howell et al., 2003). The IE values can be used to estimate the amount of water saved that would otherwise return to the system from the farm as either surface run-off or deep percolation.

Table 2.4.4: IE values from CPF and WSCLU of furrow, overhead sprinkler, drip and big gun irrigation

				CU and SWB values (in)				*Irrigation Practice*		*Irrigation Efficiency (IE)*	
Site	*Crop*		*Year*	*CPF*	*WSLCU*	P_{eff}	ΔS	*method*	*rate (in)*	*IE CPF*	*IE WSLCU*
HN-B-F1	yellow onion		2014	29.5	---	5.88	---	furrow	32.1	73.6 %	---
HN-B-D	yellow onion		2014	32.9	---	5.88	---	drip	19.6	---	---
HN-B-F2	corn grain		2014	19.0	---	5.88	---	furrow	39.4	33.3 %	---
RN	corn grain		2014	23.0	---	5.88	---	sprinkler	23.8	71.9 %	---
MK	spring barley		2014	17.3	---	5.00	---	furrow	60.5	20.3 %	---
HN-B-F	yellow onion		2015	29.6	17.2	7.36	+ 1.59	furrow	72.0	30.9 %	13.9 %
HN-B-D	yellow onion		2015	37.1	29.3	7.36	+ 3.26	drip	26.0	---	96.0 %
HN-R-F	alfalfa		2015	27.8	29.4	7.36	+ 4.76	furrow	70.8	28.9 %	33.3 %
RN	alfalfa		2015	7.9	6.1	1.51	- 2.51	sprinkler	24.4	23.7 %	17.0 %
HW-F	grass hay		2015	21.2	30.2	8.86	+ 3.32	furrow	147.2	7.4 %	14.8 %
HW-P	grass hay		2015	24.4	18.1	3.07	- 1.13	sprinkler	21.3	69.3 %[‡]	67.0 %
MK	cover crop		2015	---	7.39	1.28[§]	- 0.36	big gun	11.3		52.4 %
HN-B-F1	yellow onion		2016	39.1	22.9	4.23	+ 0.62	furrow	48.6	---	38.9 %
HN-B-D	yellow onion		2016	35.4	25.6	4.23	- 3.42	drip	20.8	---	88.4 %
HN-R-F	corn grain		2016	23.0	26.9[†]	4.23	+ 4.00	furrow	143.2	13.1 %	16.3 %
HN-R-L	corn grain		2016	20.5	20.4[†]	4.23	+ 2.62	sprinkler	30.2	53.9 %	58.6 %
HW-F	grass hay		2016	19.7	28.6	8.57	+ 1.97	furrow	103.5	10.8 %	19.7 %
HW-P	grass hay		2016	---	---	8.57	---	sprinkler	14.2	---	---
RN	alfalfa		2016	33.0	34.7	3.91	+0.48	sprinkler	37.1	78.4 %	84.1 %
MK	corn		2016	19.0	17.5[†]	5.36	+1.69	big gun	21.7	62.9 %	60.7 %

[†] Added 1.0 inches to ET rate since the evaluation period did not include April 25-May 20 (for HN-R, 2016) and May 7-June 7 (MK, 2016). The addition of 1.0 inches is a conservative amount and is most likely larger, perhaps by a factor of 2.

[‡] Used the complete season precipitation (8.86 inches from Apr 1- Sep 30) for the crop production function efficiency, since entire season resulted in actual crop.

[§] Only that occurred during the evaluation period was used.

The amount of water applied to crops at what times compared to actual crop demands throughout the growing season. is described by the NRCS supplies seasonal irrigation requirements for various crops (NRCS, 1993) in Chapter 2 “Irrigation Water Requirements.” During the 2016 field season, data was gathered on crop growth stage for alfalfa, corn and onion. These data can be evaluated against the timing of irrigations at the NCB Evaluation Sites where these crops were grown.

The improvements in efficiency documented in the project provide evidence that wider adoption of the innovations could play some role in improving water quality in the Gunnison River Basin, though the impacts would be mixed. Observation wells, for example, showed minor evidence of deep percolation at HN-B (drip), RN (pivot), and both HW-F (pivot) and HW-F (sprinkler). Deep soil sensors show similar lack of deep percolations at both HN-R (linear move) and HN-R (furrow). After the big gun irrigation system was installed at MK, evidence of deep percolation all but disappeared. Most losses appear to be tailwater, in particular at the furrow sites, such as the HN-B (furrow) site.

In addition to the previously attributed direct benefits of increasing water availability, yield and crop quality, it is hoped that results from the NCB Evaluation could support solutions to address other natural resource concerns associated with water quality concerns such as endangered fishes. The lower reaches of the Gunnison River Basin are occupied by sensitive native fish species. These include the Colorado Pikeminnow and Razorback Sucker, which are endangered species, as well the Roundtail Chub, Flannelmouth and Bluehead suckers which are species of special concern in the Gunnison and Colorado River.

While these concerns are somewhat secondary to the primary concerns of water supply, proponents believe that the irrigation improvements can play a significant role in improving aquatic habitat for these sensitive species, especially in the context of other regional efforts. Together with a series of watershed-based activities that are focused on selenium and salinity control (i.e., STF, SMP, PBO, ROD flows) focused primarily on off-farm project implementation have led to reduction in selenium levels with published reports delineating clear declining trends in the Gunnison River Basin. (USGS 2016).

2.5 Project Benefits and Lessons Learned

The lessons learned in the NCB Phase I field evaluations were used as a conceptual model for building capacity, both advisory and technical, to support approaches that might encourage producers to adopt newer methods for improving the efficiency of agricultural water use. A succinct summary of this model was developed from observations and direct survey results from project participants, indicating that 1.) *motivation, 2.) understanding and 3.) developing confidence* were key drivers in the behavioral dynamics and capacity building and the potential adoption of new agricultural practices.

Motivation is needed to drive participation in agricultural trials; to overcome uncertainty a good level of **understanding** is required and finally **confidence** must be gained in the process to maintain dedication to the 'cause'.

To break this down further:

- Motivation is the initial driver for participation and a local champion (i.e., currently a small group of producers, the NCB EC) is important for NCB type projects to be successful (e.g., Colorado River District, UVWUA, Conservation Districts in future?)
- Understanding is needed in the research and evaluation phase of the project to obtain 'buy-in" which supports eventual behavioral and technical changes needed to lay the groundwork for broader adoption.
- Confidence in the process within a trusted producer-driven and scientifically guided process is an excellent framework to encourage use of new management and technical tools - for example: gain confidence enough to support broadscale adoption and deal with skeptics (backed up by NCB project data and findings)

2.5.1 Motivation Step/Process

Soon after the drought of 2012, an ad-hoc group of farmers, ranchers, water professionals and environmentalists got together, motivated by a nagging question: "is there a better way to deal with periodic water shortages and the seemingly intractable competition for water resources? The initial premise of the NCB Partnership was that efforts focused on matching identified grower needs with targeted funding could accomplish objectives related to practices that could assist with soil health improvements while helping to stabilize water use (matching supply and demand).

From the beginning and throughout the project, the NCB Partnership has been committed to the idea that improved agricultural water delivery and innovative irrigation systems could help address a series of identified issues, including the concerns presented by the Gunnison Basin Dilemma.

What became clear during the process of capacity budling was that farmers have different sets of motivations than water resource planners and that these motivations need to be acknowledged for efficient irrigation systems to gain interest.

A key motivation that emerged was the that recognition that the relative advantage of irrigation efficiency technology supported investment of time, energy and resources more realistically for systems where niche-specific farming and higher-value cropping were integral to business models. These farming operations therefore represented more suitable targets for irrigation efficient investments by farmers and funding entities. This motivation partially alleviates a concern often raised about efficient irrigation systems, which is that efficiency gains might lead to increased consumptive use of water. When compared side-by-side for similar drops, the data collected in NCB Phase I illustrates this possibility. Because relatively lower profit operations are less likely to adopt irrigation efficient systems without financial support the motivation of higher profitability through conversion to lower CU alternatives to forage crops, for instance, can help offset crop CU increases, thereby achieving the mutual goals of increasing farm profitability and reducing losses caused by seepage, associated consumption by non-beneficial plants and numerous water quality impacts stemming from furrow irrigation practices.

Evidence of this motivation was shown by the examples of farmers that had adopted efficient irrigation systems to support niche-market farming (TK-organic, HW-grass fed beef), higher-value horticultural crops (HB-onions) or to support beef cattle operations (RN and MK).

2.5.2 Project Evolution and Understanding

The NCB project proponents spent considerable time on the process of developing a process to increase understanding in an effort to support the both the primary and secondary tasks spelled out in the original project scoping. The NCB Irrigation Evaluations focused on providing valuable, farmer-tested research data to agricultural producers, governmental organizations and water managers in order to increase understanding of these method and build local capacity.

This data issues are necessary to increase understanding of innovation irrigation systems, primarily through active farmer participation, which has been proven to be an important aspect of capacity building (Pape and Prokopy, 2017). While the theory of “farmers listening to farmers” is sound, it is also a fact that their social networks are less organized. The positive side of focusing on increased understanding gain more specific understanding of challenges with implementation, lay groundwork for broader adoption and acquire feedback is essential to address misconceptions of efficiency. The negative side that must be addressed producers are not professional communicators in situations where clear communication amongst producers is necessary, which supports the need for technical experts as a bridge to increase understanding of these tools among farmers. This is a crucial gap that needs to be addressed for understanding to develop, since communicating about irrigation innovations is not possible unless clear understanding exists (benefits, challenges, holistic, goals, objectives, issues, benefits, drawbacks).

The NCB Partnership was able to contribute better understanding among themselves and within the region regarding the different forms of irrigation. A significant value of the inductive research performed in this project allowed the NCB Partnership to contribute to an understanding both the pros and cons of different forms of irrigation as practiced in the region.

Furrow Irrigation

Obviously, farmers in the Gunnison Basin understand the pros and cons of furrow irrigation, so this discussion is pertinent only as a comparison to understand why resistance to adopting newer forms of irrigation is so difficult to overcome.

The cons of furrow irrigation have been highlighted elsewhere in this report, but there are positive aspects to furrow irrigation that may not be inherently obvious to the general public.

The first and perhaps strongest case for furrow irrigation and one of the obvious pros is that it is cheap and relatively easy. Considering the budget constraints (particularly distance to market) that control the profit-margins of Gunnison basin producers, it is hard to justify the expense associated with the adoption of more innovative irrigation techniques. Secondly, furrow irrigation allows for reliable field management activities that are required at other stages of farming, particularly at the beginning of the irrigation season, such as seed germination, weed control, pre-wetting. These practices embody some of the more significant and inherent efficiencies in furrow irrigation and are nonetheless sensible to farmers.

Sprinkler Irrigation

The pros of sprinkler irrigation have been highlighted in other sections of this report, but it was determined that a major obstacle to adoption was the reconciliation of farmer goals and water resource management objectives. Among the positives cited by farmers who participated in this study, which confirms reports from other regions is the fact that the labor requirements of managing large fields with sprinkler systems tend to be lower, due to less time setting water and eliminating the amount of equipment activity (tillage, creasing, residue control) required under furrow.

Nevertheless, at least one producer cited numerous problems ascribed to sprinkler systems, which included the norm of being able to irrigate an entire square whole field, problems with signal telemetry and calibration, rutting of wheel tracks, difficulty planting in a circular-shaped system, difficulties with side arms meant to capture the corners of the field and the cost of electrical power to run the sprinkler. Additional negatives that were reported included the lack of support for parts, limited technical service providers and the inability to irrigate irregular shaped fields.

Drip Irrigation

The advantages of drip irrigation have been highlighted in other sections of this report, and as with sprinkler irrigation, a major obstacle to adoption was the reconciliation of farmer goals and water resource management objectives. Additional advantages of drip irrigation include the opportunity to irrigate irregularly shaped fields and to configure different planting densities such that greater yields can be achieved. Furrow irrigation only works well for beds that are separated by 30 inches at most. Drip irrigation, on the other hand, allows less spacing between beds, except where needed for equipment passes.

2.5.3 Building Confidence

The last step in the capacity-building process as undertaken in this project included the beginning of a confidence-building exercise among producers. This latter step must continue with greater support and more consistent and knowledge technical support in the region. Key to this process is giving farmers confidence to make decisions based on the drivers and barriers to adoption of these newer tools (Pearcy, 2011).

Drivers and Barriers in the Adoption of Efficient Irrigation Tech

With regards to the issues cited as being problematic to sprinkler systems, several solutions are available, which have been adopted by other farmers. For instance, the inability to irrigate the entirety of a square field and the problems with side-swing arms can be overcome by utilizing linear move systems, which are growing in popularity as industry products improve. Problems with signal telemetry and calibration are resolvable as the rural digital divide is overcome through more advanced cellular networks. The issue of wheel track rutting is solvable using a three-fold approach that involves: (1) packing wheel tracks with gravel, which is possible when (2) tractor GPS systems are configured to plant in a circular fashion, and (3) proper nozzling configurations are used. Ironically, the lack of support for parts become less of an issue as more producers adopt these innovations, which may justify the investment of outside funding. Irregular shaped fields are indeed problematic, but this issue can be overcome using big gun sprinkler systems, as was done in at least one instance. Finally, the cost of power has been overcome by local electrical providers working to develop programs that result in lower power costs during night-time hours.

Drivers and Barriers in the Adoption of Soil Moisture Monitoring

It is accurate to say that the NCB Partnership spent considerable time developing an understanding of the drivers and barriers to the adoption of soil moisture monitoring tools, going so far as to conduct outreach programs, invite commercial representatives and foster local irrigation suppliers to partner with industry. A flaw in the decision to use tension-based probes was evident as these tools were found to be difficult to use without significant field maintenance. For a number of reasons, expectations must be managed when adopting these tools. A thoughtful reporting on the drivers and barriers affecting the adoption and use of these tools is supplied by Rudnick (2017).   He points out that imperfect sensor accuracy is not totally incompatible with managing trends, since just observing the behavior of the moisture trend throughout the season is helpful in understanding soil profile behavior. Therefore, as the farmer gains more information, is drives confidence in the tool.

One of the issues discovered in this project was that the adoption of soil moisture monitoring technology is highly correlated with the selection of proper monitoring devices and availability of support to assure proper implementation techniques and management approaches that make these tools effective. Without this assistance, there are simply too many variables that play a role in diminishing support for the adoption of these tools. One of the contributions of the NCB Partnership, however, was the development of local soil characteristic curves that do make it easier for producers to understand the output from these devices. Many industry supplies admit that sensors generally require calibration (Evett, 2007), and tensiometers in particular are much more effective in perennial crop systems, yet less effective in clay soils. Both of these constraints were found to be a significant barrier in adopting soil moisture monitoring. The solution to this issue, of course, is to use the tools where they are the most effective or switch to other devices, although some producers were inclined to dismiss the entire concept of irrigation scheduling based on sensor use, based on limited and negative experience with specific sensors.

Despite their widespread use, one criticism of WatermarkTM sensors is that after prolonged drying periods in the soil, the accuracy of measurement may diminish unless soil water is rewetted to reach or exceed field capacity (~10 Cb). Deep sensors may not be exposed to this rewetting frequency and therefore may provide limited useful information for irrigation scheduling. These errors were also highlighted by Shock et al. (1998b). More recently, WatermarkTM sensors have been studied for their accuracy in comparison to other devices and sensors that measure soil moisture directly (Hanson, et al., 2000). Additionally, recent studies of Watermark accuracy suggested that these sensors tend to overestimate water concentrations and should therefore be gravimetrically calibrated to specific site applications (Hignett and Evett, 2008; Varble and Chávez, 2011).

WatermarkTM sensors have been used successfully to monitor soil water status and as a tool for scheduling irrigation (Eldredge et al., 1993; Meron et al., 1996; Mitchell and Shock, 1996; Orloff and Hanson, 2000; Shock et al., 1998a), although Rudnick (2017) reported issues with measuring electrical resistance in sandy soils at high tension and with high swelling clays, which occurred in these irrigation evaluations as well. The sensors were buried in the field at placement depths suggested for the manufacturer for various crops, taking note that these recommendations are for deep, well drained soils and many of the soils on the NCB Evaluation Sites are classified as clay loams and known to be poorly drained. The manufacturer reports that internally installed gypsum provides some buffering for the effect of salinity levels normally found in irrigated agricultural crops and landscapes, but others have noted that soil salinity can affect the accuracy of manufacturer calibrations (Hignett and Evett, 2008). Using local measurements can help improve the accuracy of the soil water characteristic curves. Chávez et al. (2011) reported accuracies of ±11% for soils of Eastern Colorado According using WatermarkTM sensors to measure soil moisture.

Section 3

NCB Phase II: Specialty Crop Research

3.1 Scope and Objectives

As NCB worked with local farmers, certain patterns emerged, which suggested that many of the project participants, particularly those in the sweet corn sector, were as (if not more) interested in the impact of irrigation decisions on crop quality as they were on quantity or yields. Promoting crop quality was therefore identified as an incentive to encourage efficient water use. Given this area of emergent focus, the NCB Partnership issued direction for a more controlled research project during 2017-2019 for NCB Phase II. This phase succeeded in applying insights gathered in NCB Phase I in order to understand irrigation impacts on sweet corn yield and quality.

Many members of the NCB Partnership wanted to understand the impact of irrigation practices on crop quality, particularly for sweet corn, which is an important specialty crop in the Uncompahgre Valley. Growers understand that sweet corn generally has higher kernel quality (i.e., sugar content, appearance, taste, etc.) when water to the plant is limited during reproductive stages, but reducing water also presents the risk of yields reductions if not timed properly.

Better understanding the "quality-driven" incentives for optimal irrigation therefore emerged as an important objective in NCB Phase II, given that the market value of these crops is driven more by their quality than the quantity produced.

Given the status of sweet corn as one of the primary specialty crops in the area, for instance, the NCB Partners recruited a number of farmers to participate in continued evaluation and research on one specific crop at sites which were in much closer proximity to each other using sector-consistent management approaches.

Sidebar: *Sweet corn (Zea mays convar. saccharata var. rugosa) is basically a hybridized variety of maize with a high sugar content, caused by naturally occurring recessive genetic mutations that control the conversion of sugar to starch in the endosperm of the corn kernel. Unlike "grain corn" or "field corn" varieties, which are harvested when the kernels mature to dryness, sweet corn is picked during the immature "milk stage." Since maturation involves the conversion of sugar to starch, sweet corn must be eaten shortly after harvest or at least frozen, before the kernels become tough and starchy. The timing of irrigation, particularly during the milk stage of the crop, can highly affect the sugar content of the crop and ultimately its market value. Though affected by local environmental conditions, kernel sugar concentrations have been observed to attain their peak at approximately 20 days after pollination (Khanduri, et al. 2011).*

The majority of sweet corn in the Uncompahgre Valley is grown under furrow irrigation, which is a significant but not insurmountable obstacle to irrigation efficiency. For example, many growers in the area irrigate every other furrow, a practice that has been shown to improve soil nitrogen (N) fertilizer use efficiency and the amount of N applied (Hefner and Tracy, 1995; Nelson and Al-Kalsi, 2011), while at the same time halving the amount of water applied, reducing sediment loads and salinity in return flows. Grower confidence in alternate furrow irrigation shows that farmers are amenable to irrigation-efficient practices when cost-savings are proven. Building confidence in other "quality-driven" irrigation practices could also advance parallel demand management goals.

Previous research indicates that risks to crop yields are negligible for efficiently managed irrigation. Trout and DeJonge (2017), for example, reported that the difference in maize yield was not significant between plants receiving irrigation at 100% ET requirement versus 85% ET requirements. Ertak and Kara (2013) also documented that deficit irrigation (defined as 70% of field capacity per irrigation) caused non-significant effects on sweet corn yield but produced the highest protein content and sugar contents in a replicated study of irrigation rates. These studies support the idea that optimal irrigation could benefit the sweet corn sector in the Uncompahgre Valley, given that reliably better quality (i.e., sweeter) sweet corn fetches better prices. Higher prices, in turn, help to overcome higher transport costs from the Uncompahgre Valley to markets. Always looking for ways to improve their economic security, the market advantages to be gained by growing high quality specialty crops resonates with many farmers. By switching to higher value crops that are made possible, the efficiency savings from conversion to more innovative irrigation systems can be part of the toolkit to address current agricultural shortages, environmental flows, or other water needs in the Basin.

3.2 Selection and Design of Field Sites

During NCB Phase II, some use of deductive research principles was more feasible, given that tighter control of the variability between sites was imposed. NCB Phase II took place during the 2017, 2018 and 2019 growing seasons in the Uncompahgre Valley of western Colorado. Montauk variety of sweet corn was grown, as it is common to the area. Field sites were selected whe.re soil type, tillage, irrigation, chemical applications and fertilization practices were similar. Water was applied using furrow irrigation under siphon tubes, gated pipe, single-outlet canal gates on cement ditches and sub-surface drip lines. All farmers followed their normal irrigation management for rate and timing. All project participants used deep tillage and bed shaping practices (except the drip-irrigated field).

Sidebar: *Alternate furrow irrigation can reduce subsurface drainage and runoff, while also moving salts from the wet furrow across the bed and away from the seed row. Studies vary on the benefits of this practice, which has also been shown to cause yield reductions.*

Table 3.2.1 NCB 2019 Evaluation Sites

GPS Coordinates		
Station	***Latitude***	***Longitude***
90	38.48972°	-107.91165o
91	38.68870°	-108.07471o
92	38.59533°	-108.06048o
94	38.59627°	-108.05670o
112	38.64804°	-108.08665o
113	38.63992°	-108.09448o
553	38.68519°	-108.06937o
554	38.48817°	-107.96218o

3.3 Methods and Materials

Data was collected for each field site at a station located approximately 75% of the total field distance downfield from the irrigation source at the furrow-irrigated sites. The same selection of location was applied to the drip-irrigated fields. The data collection stations were equipped with sensors and data loggers for measuring variables of interest. Sweet corn ear samples were taken inside a 10-foot radius around the sensing stations.

Temperature

Maximum and minimum daily temperatures were needed to calculate growing degree days. Most of the field sites were equipped with HOBO 8K Pendant® Temperature Data Loggers (Onset Computer Corporation, Bourne, MA). In some instances, however, the installation of data logger was not possible or the data logger was lost, damaged or otherwise rendered inoperable. In these instances, maximum and minimum temperatures were obtained from the local Colorado Agricultural Meteorological Network (CoAgMET) station in Olathe, CO (oth01).

Growing Degree Days

Maturity time for sweet corn is between 69 and 79 days (Taber and Lawson, 2005), but can vary considerably depending on solar radiation, photoperiod and temperature, all of which influence crops differently when they are planted on different dates, as was the case with the field sites in this study. Because this aspect is almost unavoidable when working on actual farms, a more reliable method than calendar days was needed to normalize the data and compare specific points of crop development.

Growing degree days (GDDs) are a simple representation of a physiological crop development process affected by accumulating heat units. Sweet corn has a base threshold temperature of 50°F, under which significant crop development is not expected. An upper cutoff temperature of 86°F is used, above which available heat units do not promote any significant crop growth. The 86°F level adjusts the heat units for low humidity and moisture stress conditions that occur at high temperatures. It is worth noting, however, some evidence suggests that irrigated conditions may allow an upper cutoff of 93°F (Taber and Lawson, 2005), but the National Weather Service calculates GDD = $[(T_{max}+T_{min})-50]/2$, where $T_{min} = 50$ if $T_{min} < 50$°F and $T_{max} = 86$ if $T_{max} = 86 >$. The T_{max} and T_{min} are the maximum and minimum temperatures in a 24-hour period.

Evapotranspiration

Seasonal ET rates were calculated using data from the local CoAgMET station in Olathe, CO (oth01). The ASCE Standardized Daily equation was used with crop coefficients for sweet corn at different growth stages. Published values for alfalfa-reference crop coefficients ($Kc_{ini} = 0.25$, $Kc_{mid} = 0.95$, $Kc_{end} = 0.33$) and fractional growth stages (0.22, 0.56, 0.89) corresponding to these coefficients (NRCS, 1993; BMAFF, 2011). The growing season for sweet corn in the Uncompahgre Valley is approximately 90 days. Planting generally occurs in mid to late May and harvest is in late July to early August.

Certain field sites were also equipped with atmometers in 2018. These are inexpensive, simple, low maintenance tools for estimating ET (Broner and Law,1991; Alam and Trooien, 2001) available commercially (ETgage Company, Loveland, CO). It has no contact with the soil, so it is not influenced by irrigation or field practices. A canvas cover is used to simulate alfalfa-based reference ET and farmers can then correct the atmometer observations using crop coefficients to obtain estimated ET rates for their crops. Gleason et al. (2013) compared the accuracy of atmometers against the ASCE Standardized Equation and observed daily underestimation 88% of the time, with an average underestimation of 0.05 inches per day. These authors noted that underestimation reported by the atmometer was most frequently correlated with higher wind speeds.

Crop Yields

Sweet corn yield is measured differently than field corn or silage yields, for which units of bushels/ac and tons/ac are used. Instead, sweet corn growers base their yield on market quantities, commonly in boxes per acre. Boxes are measured not by weight but instead by the number of hand-picked ears they contain. Boxes are generally set to contain 4 dozen ears but may contain between 45 and 48 ears, rendering this yield measurement somewhat unreliable.

At the time of harvest, ear circumference (girth) was measured on 10 ears randomly collected within the vicinity of the sensors at each field. This measurement was useful in determining actual ear weight and biomass yield. A linear relationship ($v = 110.27c - 395.81$; $R^2 = 0.97$) was found between ear circumference (c) and ear volume (v), which was measured by immersing the corn ear in a graduated cylinder. Another relationship ($d = -0.1692c + 2.7539$; $R^2 = 0.90$) was then determined between ear circumference (c) by associating the ear mass and corresponding density (d). Circumference is also correlated with the number of rows per ear. Ear length was also measured as a proxy for kernels per row. Stand counts were done after plant emergence by counting the number of plants along 17.5 ft and 13.2 ft transects for 30 inch and 40 inch rows, respectively, representing 1/1000-acre.

Stand counts were converted to stand density (plants/ac) and two measurements of biomass production were calculated in pounds per acre (Y; lb/ac) and pounds per 100 plants (P_{100}; lb/100-plants), using the above relationships between ear size and weight. Normalized measurements allowed biomass production to be compared between sites that were planted at different densities.

Crop Quality

This project used °Brix to measure sweet corn quality. This project is consistent with the work of others (Zhu, et al., 1992; Bumgarner and Kleinhenz, 2012) who discourage the measurement of °Brix as a test of actual sugar content, but still recommend it as an indicator of quality and sweetness. One degree °Brix is considered equivalent to 1 gram of sucrose in 100 grams of solution and represents the soluble solids concentration (SSC).

Kernel °Brix was measured by reducing sweet corn kernels to an aqueous solution that could then be placed in an Atago PAL-1 refractometer (Atago USA Inc., Bellvue, WA). Some evaluations (Hale et al., 2005) caution the reliability of refractometers in correlating sugars and SSC, so kernels were also periodically evaluated for flavor. For each measurement, six ears were harvested randomly within a 10-foot radius of the moisture sensing station when plants were at the R1 or “silking” stage. Ears were then kept in an iced cooler and taken to a controlled indoor location for °Brix analysis. Kernels were removed from the ears using a Kernel Kutter™ and then juiced using an Aicok® Model AMR521 juice extractor. The pulverized juice was then strained through 20 μm filter paper and then tested in the refractometer. These measurements were taken approximately every 200 GDD as the stage of the plants progressed from V12 to harvest.

Soil Analysis

Based on early season soil testing, the fields had an average residual nitrogen (N) level of 95 ppm, indicating no N-limitations. Fields were also affected significantly by pests or weeds, given that the farmers adhered to practices recommended by the company with which they contracted to grow sweet corn. Pesticide applications were done by airplane. The common practice is to apply Gemstar® several times during the season for corn earworm and Bifenture® at the end of the season for several insects, predominantly mites.

Soils in the area are primarily clay, clay loam or sandy clay loam with organic matter levels ranging from 1.0-1.5 %. Based on data collected in the selection phase, average pH, soluble salts and cation exchange capacity levels are 7.9, 1.0 mmhos/cm and 20.2 meq/100g, respectively. Sweet corn is generally reported as having a salt tolerance threshold of 1.7 mmhos/cm. Laboratory (Midwest Labs, Omaha, NE) evaluations for soil health showed a range of 3.2 for furrow-irrigated clay versus 7.2 in a drip-irrigated sandy clay loam.

Soil Volumetric Water Content

Each furrow-irrigated site had one EM50G data logger and multiple 5TE capacitance sensors (METER Environment, Pullman, WA) installed at approximately two-thirds of the distance downhill of the water supply. For the drip-irrigated system the sensor setup was installed in the center of the field. Data from the sensors was accessible by each farmer through the https://zentracloud.com/ website through the season.

The 5TE sensors measure volumetric water content (VWC), bulk electrical conductivity (EC), and soil temperature (°C). The 5TE sensor measures the dielectric permittivity of the surrounding soil using an electromagnetic field and the stored charge is proportional to the soil VWC. The 5TE sensors were installed at different depths in order to measure water content in the full root zone. In 2018, each site was equipped with three sensors at depths of 6, 12 and 24 inches. In 2019, each site was equipped with two sensors at depths of 8 and 20 inches, along with shallow monitoring wells and HOBO 8K U20 Series Water Level Loggers (Onset Computer Corporation, Bourne, MA). The number of capacitance probes was reduced at the sites in 2019 due to equipment damage budget constraints on the project. The deep sensor, however, was largely used to confirm deep percolation or potential capillary rise.

Irrigation Rate and Volume

Irrigation rates and applied volumes were calculated based on the length of irrigation set (supplied by the producer), number of sets (evident from the soil moisture sensors) and knowledge of the irrigation system. Martin (2011), provides expected delivery rates for various types of surface-irrigated systems. During the 2017 and 2018 cropping season, producers irrigated 1-¼" siphon tubes, except for one producer who used a concrete ditch with single outlet canal gates and another producer who used a subsurface drip irrigation (SDI) system. During the 2019 cropping season, producers with surface irrigation used 8" gated pipe, except for one producer who continued to use 1-¼" siphon tubes. The producer with the SDI system also remained in the evaluation.

3.4 Results and Discussion

Average planting dates for 2017, 2018 and 2019 were 5/4, 5/18 and 5/29. Average harvest dates for 2017, 2018 and 2019 were 8/11, 8/11 and 8/26.Total precipitation was less and temperatures were generally hotter in 2018 compared to 2019. Relative humidity (RH) levels were greater through 2019. Solar radiation levels were approximately 6% greater in 2018 compared to 2019. In general, the 2018 sweet corn season could be described as "warmer and drier" than the 2019 season, which was "cooler and wetter" with the exception of August 2019 when temperatures rose considerably. The 2017 season experienced weather in the range between the 2018 and 2019 conditions.

Table 3.4.1 Meteorological Data for the Research Region (CoAgMet oth01 Station, Olathe, CO)

Climate Factors	**Year**	**Month**					**Total or Average**
		April	May	June	July	August	
Precipitation (inches)	2017	0.25	0.65	0.00	0.91	1.57	3.38
	2018	1.02	0.32	0.20	0.26	0.40	2.20
	2019	1.91	0.79	0.75	1.07	0.01	4.53
Average Temperature (°F)	2017	48.88	57.78	70.89	74.18	69.99	64.34
	2018	51.43	61.80	71.03	75.30	71.12	66.14
	2019	50.98	53.41	65.32	73.12	73.17	63.20
Average Maximum Temperature (°F)	2017	65.87	74.07	91.04	91.78	87.81	82.12
	2018	68.05	80.82	90.97	94.12	89.82	84.76
	2019	67.24	68.25	83.48	93.41	95.27	81.53
Average Diurnal Temp Difference (°F)	2017	33.98	32.58	40.29	35.21	35.64	35.54
	2018	33.25	38.04	39.89	37.65	37.39	37.24
	2019	32.53	29.67	36.33	40.59	44.21	36.67
Relative Humidity (%)	2017	0.45	0.48	0.39	0.55	0.57	0.49
	2018	0.43	0.40	0.37	0.49	0.51	0.44
	2019	0.53	0.56	0.50	0.51	0.51	0.52
Solar Radiation (MJ/m^2)	2017	21.57	23.71	25.05	16.81	20.27	107.40
	2018	19.43	23.70	27.34	24.82	21.19	116.48
	2019	18.25	20.33	24.62	24.26	22.28	109.74

See Figure 3.1 for the plot of Cumulative GDD vs Date (2017, 2018, 2019)

Average growing degree days (GDDs) between emergence and harvest for the 2017, 2018 and 2019 seasons were 1816, 1564 and 1554 (Figure 3.1). The difference between 2017 and subsequent years was related to the length of time that crops were in the field. Most fields in 2017 and 2018 were planted in early to mid-May, but most fields in 2019 were planted closer to the end of May, resulting in an approximate 11-day delay past the typical planting date for the region. There was almost no difference in cumulative GDDs between 2018 and 2019, but monthly temperatures varied widely throughout the season. Another notable difference existed between the reproductive stages and ripening period in 2017 and 2018, versus 2019. The delay in planting in 2019 resulted in sweet corn maturing to the R1 stage during the latter part of August that year. The diurnal temperature differences were much greater during the 2019 ripening period (early August) as compared with the 2018 ripening period (late July) (Figure 3.2). The average diurnal temperature variations for the final 20% of the growing season (based on GDD) were

40°F and 46°F, respectively, for 2018 and 2019, reflecting an 18% increase in 2019. Similarly, average maximum temperatures during the same period were 92°F and 96°F, respectively, for 2018 and 2019. See Figure 3.2 for the plot of Temperature vs. Date

Evapotranspiration

Crop water use totals for 2017, 2018 and 2019 were estimated at 15.0, 15.2 and 13.4 inches during the period between planting and harvest for each season for our study and depicted in Figure 3.3. The average seasonal ET requirement of irrigated sweet corn across several Western Colorado locations has been reported by Schneekloth and Andales (2017) at 19.7 inches, but Wendt et al. (1977) estimated ET at 14.2 inches using a water balance approach in another study comparing furrow, sprinkler and drip irrigation systems on loamy fine sand soils in Texas. Wendt et al. (1977) also found no significant difference in ET for these different irrigation methods. See Figure 3.3 for the plot of Temperature vs. ET Rate

Sweet Corn Yield and Quality

Yield data is summarized in Table 3.4.2. Because this study was not designed as a replicated trial under controlled conditions, it is difficult to isolate causal factors, but some generalizations and observations can be made regarding yields, based on biomass measurements and ear sizes.

Table 3.4.2 Sweet Corn Yields, Dates and Sizes

						Stand Ct	Corn Ear Characteristics				Yield	
Site	**Year**	**Plant**	**Harvest**	**Days**	**GDD**	(plants/ac)	length (in)	cicum (in)	volume (in^3)	mass (lb)	(lb/100)	(boxes/ac)
113	2017	4/25	8/6	103	1686	---	---	---		---	---	514
420	2017	5/15	8/12	89	1657	---	---	---		---	---	517
553	2017	5/20	8/15	87	1918	---	---	---		---	---	415
554	2017	5/17	8/15	90	2005	---	---	---		---	---	532
				92								*495*
90	2018	5/23	8/17	86	1590	23,600	8.50	6.40	18.87	1.14	115	372
91	2018	5/29	8/19	82	1522	21,600	8.48	6.20	17.55	1.08	112	---
92	2018	5/26	8/15	81	1531	21,000	8.28	6.11	16.94	1.05	102	360
94	2018	4/28	7/31	94	1670	22,600	8.18	6.87	22.02	1.27	128	433
112	2018	5/20	8/11	83	1472	23,600	8.48	6.31	18.31	1.12	112	482
113	2018	5/26	8/16	82	1482	23,400	8.52	6.31	18.31	1.12	113	401
553	2018	5/12	8/13	93	1652	22,000	8.44	6.13	17.10	1.06	105	366
554	2018	5/11	8/6	87	1590	23,600	8.05	6.15	17.19	1.07	101	426
Average				*86*	*1564*	*22,675*			*18.29*	*1.11*		
90	2019	6/1	8/29	89	1598	28,333	8.15	6.60	20.24	1.20	120	437
91	2019	5/31	8/25	86	1544	28,333	8.25	6.75	21.25	1.24	124	475
92	2019	6/1	8/29	89	1518	29,000	7.55	6.40	18.90	1.14	114	461
94	2019	5/31	8/30	91	1555	27,000	8.33	7.73	27.81	1.45	145	475
112	2019	5/14	8/18	96	1646	26,333	8.56	6.63	20.44	1.21	121	448
113	2019	6/1	8/26	86	1550	29,333	7.55	6.53	19.77	1.18	118	477
553	2019	5/31	8/24	85	1487	26,333	8.00	6.23	17.75	1.09	109	---
554	2019	5/31	8/27	88	1537	26,333	8.00	6.65	20.58	1.21	121	441
Average				*89*	*1554*	*27,625*			*20.84*	*1.22*	*122*	*459*

Sweet corn ears were significantly ($p < 0.05$) greater on average by 3.8% in 2018. Although ear length will tend to vary among varieties, this study involved only one variety (Montauk) so genetics was not considered a factor. Ear lengths are dependent on conditions during vegetative stages prior to R1 (silking), since the number of kernels per row is set prior to reproduction. Good pollination is necessary to produce more kernels, so the lower planting densities in 2018 could have been a factor influencing the ear lengths. Taber and Smith (2001) reported that length of marketable sweet corn ears may increase as plants consume more water, which would be consistent with the higher ET rates prior to silking (R1) in 2018 for this data. Between planting and 1000 GDDs, for instance, the ET demands for 2018 and 2019 were 8.51 and 7.17 inches, respectively. Despite the large difference in June and July ET demand for these years, plants were not likely under-watered between planting and silking in either year, given the nature of furrow irrigation.

Sweet corn circumferences were significantly ($p < 0.05$) greater on average by 6.0% in 2019, indicating fuller kernels. A number of factors could have contributed to this difference, such as the plant population, temperatures, irrigation rates, or availability and timing of nitrogen (N), although the exact cause cannot be determined based on this study design. Plant populations were higher in 2019, but the potential leaf shading may have affected photosynthesis through leaf shading, and caused N to be directed to the kernels instead of leaves. Further communication with producers will be conducted to determine if there was any evidence of kernel sizes being affected by plants experiencing colder conditions. As reported by the producers, no pressures from drought, insects, frost or cultivation damage occurred at these sites.

Irrigation may have been a factor affecting yields. Optimal irrigation is a challenge under flood-furrow, which is generally less than 50% efficient, so many of these fields would be considered sub-optimally irrigated due to excess watering. Ertek and Kara (2013), for example, reported the highest sweet corn yields under irrigation regimes supplying water at rates between 85% and 100% of ET, but little is known specifically about sweet corn yields above 100%. Irmak (2015), however, reported curvilinear relationships between seasonal irrigation amounts and yield, which increased as irrigation approached 100% ET requirement, but then diminished when watering exceeded these levels. These reductions can be attributed to reduced oxygen in the root zone and increased likelihood of N leaching (Kanwar et al.; 1988; Irmak, 2015).

Biomass production in 2019 was greater by 9.5% than in 2018, attributing to the bulkier ears and fuller kernels. Biomass produced, P_{100}, averaged 111 and 122 lb/100-plants for the 2018 and 2019 seasons and was significantly different ($p < 0.05$). Larger ear sizes also corresponded to more boxes per acre.

Based on the observed data, the simplest explanation is that some combination of slightly more desirable weather and N availability during grain fill contributed to better yields in 2019. Bhatt (2012), for example, documented the maximization of numerous attributes (length, circumference, weight, total kernels) based on N availability. Ciampitti and Vyn (2011) also reported that higher plant densities may increase nitrogen use efficiency (NUE). Since these fields are furrow-irrigated, some N was probably flushed from the soil, also affecting overall N levels, but slightly better weather conditions likely promoted higher NUE.

A general observation that can be made from this data is that the longer ears in 2018 suggest more water was consumed early season, but even by letting soil dry a bit more in 2019, the ear lengths were not substantially affected. In fact, this outcome may have helped to have possibly preserved more N in the soil. Additionally, even with the late season drier soils in 2019 and lower ET rates at that time, the ear circumferences were greater. This would suggest that plants either consumed more N at this time, and/or were more efficient with the N they consumed or both.

Table 3.4.3 Sweet Corn Quality Data (2018 and 2019)

Between the blistering (R2) and milking (R3) stages, °Brix levels increase rapidly as sugars accumulate. One result worth highlighting is that the final °Brix levels in 2019 were 10% greater than in 2018 despite almost identical GDDs during the R2 and R3 stages for both seasons. Given that no major changes to irrigation were imposed, a possible explanation for this result is the difference in weather during the R2 and R3 stages in both years, due to the later date of planting 2019. Mean daily and maximum temperatures were much higher towards the end of 2019, for instance, compared to the same period from 2018. The diurnal temperature difference was also significantly larger in 2019 during R2 and R3. Although heat units above 86°F do not generally increase GDD, the effect of temperatures greater than 86°F could certainly have influenced sugar formation.

Another interesting result was the difference in the *rate* of sugar accumulation during both seasons. This rate, referred to in this study as the °Brix gain rate (BGR), can be calculated on a daily basis or on the basis of GDD. The BGR on a GDD basis was therefore calculated for the period between R2 (which occurred around 1400 GDD) and the highest final measurement. Similarly, the number of days between these two points was also used for BGR on a daily basis. The BGR was deemed by farmers to be a more useful parameter in this study, since the final °Brix reading is purely a consequence of the harvest date driven by the sweet corn market. The BGR is also more useful for comparing the reaction to environmental and weather conditions. Please see Figure 3.4 for a plot °Brix vs GDD (2018 and 2019).

The general conclusion for 2018 was that sweet corn was sub-optimally (excess) irrigated, but timing was also a factor that may have affected N in the soil. The sweet corn °Brix levels also benefited from higher temperatures and these benefits were not overwhelmed by extra water. In contrast, growers recognized that sweet corn was of a higher quality in 2019, based on the °Brix concentrations and the overall ear weight of the sweet corn. Please see Figure 3.5 for a matrix plot of BGR vs ear weight per 100 plants for 2018 vs 2019.

As mentioned earlier, soils were allowed to dry a bit more in 2019, but ear lengths were not substantially affected and ear circumferences were greater. Biomass production was greater as well. The plants either consumed more N, were more efficient with the N they consumed or both. The °Brix levels were also higher and gained faster in 2019, which could be explained by a combination of better soil water conditions and higher diurnal temp swings.

Irrigation

Sweet corn can tolerate being under-watered during the period between planting and tasseling (VT) without much effect on yield or quality, but maintaining soil moisture at about 40% MAD is recommended (Van Denburgh, 1998). Because the most critical periods of water demand in sweet corn occur during its reproductive stages, even a 3- to 4-day period of water stress during this time can cause significant yield reductions. Most farmers will therefore opt to use visual cues to irrigate by crop growth stage during this time, rather than use weather-based or soil-based scheduling approaches. Raising soil moisture to 60% MAD before (10-12 days) tasseling and up to 70% MAD during silking and pollination is also recommended (Van Denburgh, 1998).

The irrigation data collected in 2018 and 2019 are summarized in Table 3.4.3.

Table 3.4.4 NCB Sweet Corn Irrigation Data (2018 and 2019)

			Furrow Length		Irrigation Applied During GDD percentiles (inches)										
Site	**Year**	**Method**	(ft)	**Total Sets**	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	TOTAL
90	2018	1-½" Siphon Tubes	1198	11	10.97	0.00	5.48	10.97	5.48	5.48	10.97	5.48	5.48	5.48	65.8
91	2018	Subsurface Drip	---	---											
92	2018	1-¼" Siphon Tubes	1224	12	7.70	0.00	0.00	3.85	7.70	3.85	7.70	3.85	7.70	7.70	50.0
94	2018	1-½" Siphon Tubes	765	13	12.18	0.00	6.09	6.09	6.09	12.18	18.27	6.09	12.18	6.09	85.3
112	2018	1-½" Siphon Tubes	1209	11	10.87	5.43	0.00	5.43	5.43	0.00	5.43	10.87	10.87	10.87	65.2
113	2018	1-½" Siphon Tubes	1288	11	10.20	5.10	0.00	5.10	0.00	5.10	10.20	10.20	5.10	10.20	61.2
553	2018	1-½" Siphon Tubes	644	9	14.47	7.24	0.00	14.47	0.00	7.24	7.24	7.24	7.24	7.24	72.4
554	2018	1-½" CDSOCG	1520	12	8.64	6.48	0.00	6.48	12.97	6.48	6.48	12.97	12.97	6.48	80.0
Average															*68.5*
90	2019	10" Gated Pipe	648	11	11.41	11.41	5.70	5.70	11.41	5.70	5.70	5.70	11.41	5.70	79.9
91	2019	1-¼" Siphon Tubes	1178	11	8.00	0.00	4.00	4.00	4.00	8.00	4.00	4.00	8.00	4.00	48.0
92	2019	Subsurface Drip	---	---											
94	2019	1-½" Siphon Tubes	1290	10	10.18	5.09	5.09	5.09	5.09	5.09	5.09	5.09	10.18	0.00	56.0
112	2019	1-½" Siphon Tubes	2581	11	5.09	2.55	5.09	2.55	7.64	5.09	0.00	7.64	2.55	5.09	43.3
113	2019	10" Gated Pipe	732	9	10.10	0.00	0.00	10.10	5.05	10.10	10.10	5.05	10.10	10.10	70.7
553	2019	1-½" Siphon Tubes	1249	10	10.52	0.00	5.26	5.26	5.26	5.26	5.26	15.78	0.00	5.26	57.9
554	2019	10" Gated Pipe	1245	12	7.79	3.90	0.00	0.00	3.90	11.69	3.90	7.79	7.79	3.90	50.7
Average															*58.0*

CDSOCG = Cement Ditch Single Outlet Canal Gates

Volumetric Water Content Calibrations

To offer an explanation for the clear difference between both yield and quality data between 2018 and 2019 the NCB Partnership discussed the possibility that 2018 sweet corn may have been sub-optimally over-irrigated in 2018, leading to less favorable N uptake, rooting issues, and other problems that typically arise from heavier irrigation. It is important to put this observation in some context, however. More specifically, the seasonal differences experienced by crops clearly drives ET rates, especially when they are planted at different times of the year. As has been discussed, a goal of the NCB Partnership is to advocate for transition away from furrow irrigation. The observations made in NCB Phase II point to the importance of timing irrigation and crop growth stages, such that another, perhaps more simplistic, opportunity exists to attempt better timing of flood irrigation sets with crop vegetative and reproductive stages and soil moisture conditions.

As it happens, the 2019 sweet corn crop benefitted from a more optimal irrigation regime throughout the season, although it was acknowledged that this outcome was somewhat unintentional. Nevertheless, the opportunity exists to utilize more knowledge of soil characteristics, or simply use soil water sensors as triggers to decide more optimal times to irrigate. A summary of valuable soil characteristics at the field sites is provided in Table 3.4.5.

Table 3.4.5 Summary of soil characteristics at the field sites

			Soluble Salts	CEC	Nitrogen	Soil Water Content Parameters				Soil Health
Site	Year	pH	(mmhos/cm)	(meq/100g)	resid (ppm)	Texture	FC (%)	PWP (%)	AWC (%)	Rating
90	2018	7.7	0.9	21.5	98	SCL	27.37	11.33	16.04	2.5
91	2018	8.0	0.7	17.6	30	SCL	22.08	13.03	9.05	7.2
92	2018	8.1	0.7	18.3	47	SCL	22.45	11.57	10.88	2.8
94	2018	7.9	1.1	23.3	90	CL	29.85	13.83	16.02	3.4
112	2018	8.0	0.9	20.9	67	C	29.34	13.66	15.68	2.4
113	2018	7.8	0.8	19.4	114	SCL	23.79	11.67	12.12	3.2
553	2018	7.8	1.1	19.5	121	CL	28.73	13.63	15.10	4.9
554	2018	7.9	1.7	21.1	190	SCL	25.53	11.62	13.91	3.2
Average		*7.90*	*0.99*				*26.14*	*12.54*	*13.60*	
90	2019	---	---	---	---	C	30.83	15.25	15.58	---
91	2019	---	---	---	---	CL	28.88	13.37	15.51	---
92	2019	---	---	---	---	SCL	19.54	9.77	9.77	---
94	2019	---	---	---	---	CL	25.94	11.90	14.04	---
112	2019	---	---	---	---	CL	26.62	11.69	14.93	---
113	2019	---	---	---	---	CL	24.39	10.73	13.66	---
553	2019	---	---	---	---	CL	29.87	16.33	13.54	---
554	2019	---	---	---	---	SCL	23.12	8.19	14.93	---
Average							*26.15*	*12.15*	*14.00*	

Soil moisture sensors can be as a tool for irrigation scheduling, and in a large number of cases, these sensors have been shown to increase horticultural crop yield and quality while conserving water. For example, Zotarelli et al. (2009) showed that users who manage irrigation with soil moisture sensors applied 15 to 51% less irrigation water compared to fixed-time irrigation plan and observed a tomato crop yield increase of 11 to 26%.

Several issues need to be resolved, however, before producers will find themselves confident enough to apply soil moisture sensing as a tool for deciding to irrigate. Among the most problematic issues was the fact that field measurements of volumetric water content did not conform to the expected permanent wilting point (PWP) and field capacity (FC) range as reported by laboratory analysis for the majority of the capacitance probes. Although this was expected for the 5TE sensors as the user manual indicates that these instruments were accurate to ±0.03 in/in (METER Group, Inc., Pullman, WA), some of the producers felt that these errors belied a lack of applicability for the technology.

One solution offered was to use a concept, similar to Rudnick (2017) that sensors simply be used as triggers for irrigation, based on a departure from a threshold higher water content that could be observed throughout the year. In other words, while most sensors will not calibrate precisely with laboratory analyses, the sensor in the field does still effectively represent a useful data set. Therefore, regardless of the laboratory-supplied soil data, a decision to irrigate can still be made on the basis of a generic management allowable depletion (MAD %), which is irrespective of soil type. The MAD advised for sweet corn, for instance, is generally 40% within a 24-inch root zone, indicating as a general rule that sweet corn should be irrigated when 40% of the AWC has been used to avoid stress.

Given the poor correspondence between laboratory-provided results and calibrated sensor data, the "practical determination method" (Simmone et al., 2007) should be evaluated as a strategy for optimal irrigation. This method assumes that noticeable points of inflection on the VWC curves can be used to "infer" an FC and PWP that emerge based on the trends in the data throughout the season. After each irrigation event, for example, a rapid spike in soil water content indicates that the soil is saturated above the field capacity and quickly drains as water percolates through the profile. Subsequent to this short draining period (1-3 days) the slope of the VWC curve becomes more gradual, reflecting a slower rate of water extraction caused by crop ET. The point where the drainage and extraction lines on the curve meet and the slope exhibits a clear inflection can be assumed as an estimate of FC for the soil condition in which the sensor resides. The curve can be further examined for another point of inflection where the extraction curve flattens almost to zero. This level can be assumed as a proxy for PWP. By subtracting the observed quasi-values for FC and PWP, an estimate of AWC can be made and additionally a marker for MAD.

Recommendations for more detailed research on the issue of "quality-driven" irrigation is warranted. The NCB Phase II evaluation highlighted a number of issues with methodological approaches and technology deployment that can be built upon in order to develop better relationships between crop quality and the simple concept of irrigation scheduling based either on the practical determination method or a more effective use of soil moisture monitoring tools. As observed in this evaluation, there appears to be a positive relationship between deficit irrigation and higher Brix readings in sweet corn, but this evidence needs to be scaled up and further studied in order for growers to gain more confidence in these concepts. While it may not constitute an overall paradigm shift, the concept of using simple sensing technology to achieve 10-20% less water applied to furrow irrigation would be an admittedly desirable outcome for both growers and water planners.

From the grower perspective, the NCB Phase II data points to an opportunity for strategic reductions in irrigation in order to increase °Brix levels without compromising overall yield, and the benefit to water planning in the region is obvious. An approach favored by some of the NCB Partnership participants, worthy of adoption in a few specific cases, is to determine monitor °Brix throughout the season, particularly in the reproductive stage and prior harvest after a GDD threshold (observed to be approximately 1400 GDD after planting. After sweet corn reaches 1400 GDD its vegetative state moves into the R2 phase, or "blister" and the sweet corn kernels begin to store sugar and gain °Brix levels, which is an opportune time to regulate irrigation, in practice by eliminating a late season set.

3.5 Follow-up Survey

At the end of the 2018 cropping season, a simple, non-scientific, follow-up survey was performed with the farmers who participated in NCB Phase II, many of whom also participated in the 2019 evaluation. This survey, along with the results of the field evaluations, provide some lessons learned that are applicable to the overall goals of the CWCB ATM program.

Not surprisingly, it was found that participants had a diverse set of motivations and reasonings that guided them whether to participate in new efficiency practices or not. The most common responses indicated that growers choose to participate in new practices due to two main reasons: 1.) economic justification, that is increasing profit margins and 2.) for "increased crop quality".

While "saving water" was listed as contributing factor, it was actually near the bottom of the motivating reasons by rank based upon participant responses.

3.6 Conclusions

While the land use footprint of sweet corn is fairly small, relative to other crops in the Uncompahgre Valley, the potential to build capacity around the understanding that *water use efficiency can drive quality* is large and extends well beyond this crop.

This premise that crop quality is one of the most important motivations for growers is an important tenet in the challenge of local norms for irrigation practices. As the project continued into Phase 2, confidence developed around the idea that "quality-driven" incentives for reduced irrigation could be more persuasive than demand management or water shortages. This is especially true if, when and as, project participants had invested in irrigation improvements and were involved in niche-market farming (e.g., organic, grass-fed beef) and specialty, high value crop products (e.g., onions, sweet corn).

Section 4

Extension and Engagement

It must be recognized that implementation of a successful stakeholder project involving complex and competing issues is via good outreach and communication. It is essential to address concerns and dispel common misconceptions with clearly elucidated, unbiased fact- and science-based actionable information.

This chapter outlines the recommended outreach and communication approaches and actions taken to solicit support and to provide a forum or platform for local irrigation agricultural communities to engage in efficient irrigation practices for multiple benefits.

4.1 Project Benefits and Lessons Learned

The lessons learned from NCB Phase II support the idea that farmers gain interest and adopt irrigation water management tools through the stepwise process of finding motivation, building understanding and developing confidence.

Finding Motivation. The results of the farmer survey suggest that economics are an important motivator in the adoption of irrigation management tools. A significant driver of economics in the sweet corn agricultural sector involves quality as well as quantity, as we learned in NCB Phase II. In other words, the concept of “quality-driven” approaches to irrigation water management has merit and support among farmers.

Building Understanding. The results of the farmer survey also indicated that local access to technical expertise and troubleshooting is needed as a further incentivization to change irrigation management and behavior. In other words, while motivation is a crucial first step, understanding how to use new technology is a critical next step to convert this motivation into initial adoption.

Developing Confidence. Sustained use. Practices are improved and farmers begin to adopt.

4.2 Common Misconceptions

With a myriad of complex rules that govern federal, regional and local water use, and ingrained traditions that guide local practices, it is not easy to change minds. In fact, these complexities and sometimes conflicting rules have, at the worst led to misconceptions, or at the least to misunderstandings of the issues. In turn, these misunderstandings can lead to obstacles and roadblocks to proactive changes and improvements.

A good example of this is the old adage “Use it or Lose It” that refers to water rights in Colorado. Not only is this statement an oversimplification, it is untrue in most cases. Water rights are generally protected unless expressly abandoned with intent. Many white papers and analytical publications have been written to address this concept.

4.3 Grower Participation Meetings

4.3.1 NCB Phase I

Regular periodic meetings were held with growers since the inception of the project. Hosted by the Executive Committee of NCB, and their coordinator, Steve Schrock, these meetings were set up to solicit input and to disseminate project information and findings. Such meetings were typically held monthly in Olathe, Colorado and involved the field technicians, project manager, participating growers, interested parties and guests. These meetings were supplemented with annual engagement meetings convened to review the previous year's activities and results as well as to perform planning for the growing season to come.

During Phase 1, side-by-side irrigation practice analysis, individual grower meetings were also held in the field to engage grower participants directly and to generate additional interest from neighbors and future potential participants. These opportunities were often used to review and explain technical details related to the soil moisture monitoring and measurement equipment being used for data collections. Troubleshooting was performed separately on an as-needed basis by the field technicians.

4.3.2 NCB Phase II

During Phase 2, the 'quality-driven phase' grower participation increased along with the participation and the content of the engagement meetings.

Beyond building local capacity and knowledge base, discussions evolved to include invited guests and experts to discuss and define water rights, their implementation and implications related to both privately held (e.g., individually owned, or by mutual ditch companies) and federally-owned and/or sponsored facilities (e.g., UVWUA). Difficult issues related to 'saved and salvaged water' crept into the mix with concerns about how increased water use efficiencies might impact the underlying irrigation water rights. The fear associated with uncertainty and misinformed perceptions related to this issue was likely an obstacle that kept some producers from participating in the project.

It was observed that it is difficult to change behavioral patterns and practices based upon historical understandings. Even in light of changing laws or public perception, there is a significant inertia to adopting different practices, and especially to assume additional perceived risk, without additional motivation and/or incentives.

In other words, Phase I results, where more efficient practices were demonstrated and analyzed in the side-by-side trials, did not have a significant amount of influence on changing agricultural practice behavior because the perceived reward (less water diversions) was less than the perceived risk (loss of water rights), whether real or imagined.

In Phase II, the quality-driven phase, after it was clearly demonstrated that yields were not adversely impacted by utilizing more efficient water use practices (actually applying less water) and that crop quality could be improved, a clear motivating factor, grower behavior appeared to change incrementally. This suggests that it is important to define the point at which the risk-reward relationship changes, in other words, when this relationship essentially reaches an inflection point.

The receptivity by growers to using less water via reduced water applications or irrigations, goes up significantly when increased crop quality and/or yield is demonstrated as a direct result of a more efficient practice. Thus, it is apparent that the ability to add applicable info related to enterprise budgets for quality-driven projects (e.g., sweet corn) would influence growers to more rapidly adopt BMPs such as soil moisture-informed water efficiency practices and/or decision-making that is data-driven.

This finding strongly suggests that there is a need for real time data collection and dissemination to growers to enable broad grower participation. Towards this end, it is recommended that an agricultural liaison is needed to help collect data and to interface with growers in real time to aid and support good decision making and informed use of agricultural water use BMPs.

Specifically, such a liaison could engage and educate local farmers and forage producers seeking higher quality agricultural products regarding the use of soil moisture technology and efficient water use techniques. The promotion of efficient water use, informed by soil moisture conditions in the No Chico Brush area of the Uncompahgre and North Fork valleys of western Colorado would provide multiple benefits.

In large part, this recommendation and direct finding can be attributed to David Harold of Tuxedo Corn. This outcome is a direct result of his leadership of No Chico Brush and is an excellent example of the benefits of direct agricultural producer engagement.

4.4 Engagement with other Funding and Processes

Early in the evolution of NCB, the group became active with the development of USDA Farm Bill programs and associated re-authorization processes. In particular, the NCB was integral to the development of the Regional Conservation Partnership Program (RCPP) and the designation of the Colorado River Basin as a "Critical Conservation Area". This led to a significant funding opportunity for irrigation efficiency investments in the Lower Gunnison Basin.

On behalf of the beneficiaries in the Lower Gunnison, including the NCB, the Colorado River District applied for, and received $8 million of directed funding for a series of integrated irrigation projects (i.e., construction of irrigation infrastructure improvements including conveyance piping, regulation facilities and controls). Now known as the "Lower Gunnison Project" (LGP), this project facilitates the conversion to efficient processes and practices, consistent with NCB goals and objectives.

Following the success of the No Chico Brush project, it is hoped that LGP type projects can and will be expanded. Already there are efforts to seek additional funding to expand the NCB / LGP models and associated 'grand vision' in other local sub basins. This is consistent with the Colorado Water Plan and Gunnison Basin Implementation Plan and is leading to implementation of pressurized pipelines with minimized losses together with on-farm practices with the hope that additional producers will implement and to engage in efficient on-farm practices including but not limited to subsurface drip and overhead pivots, minimum till practices and soil health practices that result in meeting a host of natural resource objectives (e.g., water quality improvement, water and soil conservation, carbon sequestration, etc.).

4.5 Website and Database

Parallel to the NCB process and in conjunction with partners such as the Nature Conservancy and the Gunnison Basin Roundtable, the website GunnisonRiverBasin.org was created. This on-line web resource serves as a clearing house for information on the NCB grand vision related to WUE practices that were investigated and developed as part of the NCB partnership.

Additionally, NCB-produced data, interim products and associated results are also archived on this website at the following weblinks:

https://gunnisonriverbasin.org/projects/no-chico-brush/

https://gunnisonriverbasin.org/projects/lower-gunnison-project/

It is hoped that this on-line resource can assist in leveraging the data and results produced by this project for associated irrigation improvement projects

Section 5

Recommendations for Future ATM Projects

The overarching goal of the NCB Partnership Project was to evaluate the benefits and challenges that farmers face when trying newer irrigation techniques. The NCB Partnership recommends that the lessons learned from this project be used as a guide for future efforts that motivate farmer interest, help them understand new approaches and build the confidence to adopt water saving irrigation approaches.

The Alternative Transfer Method Support Report (ATM Support Report, 2020) submitted to the CWCB by the Colorado Water Center in June 2020 provides useful parallels to the recommendations made in this report. The ATM Support Report offered a "*fresh look at ATM projects in Colorado to understand what role they should serve in state planning efforts and to define actions that can be taken to support ATM development and implementation*." The ATM Support Report also identified several barriers to ATMs, among which included "*research on the feasibility and limits of deficit irrigation*." This is a particularly important parallel to the work of the NCB Partnership, since farmer-led capacity building is an effective way to guide research on the flexibility and limits of deficit irrigation.

Sidebar: If baseball great, Yogi Berra, was as a farmer, he might have applied one of his famous quips about deficit irrigation: "*In theory, there is no difference between practice and theory. In practice, there is*."

Humor aside, from a practical standpoint, deficit irrigation is mostly incompatible with traditional flood-furrow irrigation, which is the dominant form of land irrigation on the Western Slope. This is because the successful implementation of deficit irrigation requires monitoring technology and precision associated with efficient irrigation systems. Specifically, effective deficit irrigation relies highly controlled irrigation water application in response to soil moisture monitoring data. Thus, it is important to convert irrigation methods away from gravity-flood systems, so that west slope farmers can play a potential role in such techniques.

While further research is always warranted, the NCB Partnership has learned that infrastructure improvements to irrigation systems, along with sustained access to technical support, are critical to the motivation, understanding and confidence needed to implement water-saving irrigation approaches, including deficit irrigation. The recommendations from the NCB project are consistent with this overarching concept and reinforce the importance of conversion to efficient irrigation practices that the CWCB and GBRT should support with financial and technical assistance.

5.1 Support for ATM Projects Focused on Efficiency

It is recommended that future ATM projects counterbalance the goals of water conservation and water savings (examples provided below). Just at the metrics of success for water conservation projects may include acre-feet conserved or transferred, the metrics of success for water-saving projects could be defined in terms of the value added in monetary profit, biomass product or water effectively by the plants, per volume of water withdrawn or applied, which can be correlated with measurable water savings. These metrics correspond, respectively, to WUE, irrigation water efficiency (IWE) and irrigation efficiency (IE). Although efficiency improvements have been made through ATM Projects in other parts of the state, they have been not been supported broadly in western Colorado, nor specifically to address the Gunnison Basin predicament. It is known that these improvements reduce headgate demands and achieve numerous environmental benefits, but they save water and can reduce consumptive use at the field scale if crop-switching occurs.

Efficiency Gains with Multi-purpose Irrigation BMPs

As a general rule, BMPs that address multiple purposes stand greater likelihood of sustained adoption and outside support. As shown in this project farmers in the NCB Partnership were shared common goals with environmental groups, such as basin-level efficiency, regional soil health, runoff salinity reduction and lower selenium loading, but they realistically point out that these purposes are not priorities that drive them to adopt more efficient irrigation systems. For farmers, irrigation BMPs need to also consider increased WUE, better profitability, labor savings, reduced inputs, and other purposes that affect their operational budgets. As the NCB Partnership points out, sustained interest in irrigation BMPs is greater when there are clear connections between on-farm incentives (improving crop quality, reducing labor costs, etc.) and ATM goals (increased river flows, sharing agricultural water, etc.).

Among the inventory of ATM projects, the Rocky Ford Continued Farming Program (Phase II) most closely aligns with the type of multi-purpose BMPs that the NCB Partnership would support. This program was set up in 2007 when the City of Aurora and the Rocky Ford Highline Canal Company worked together to develop an alternative to "buy and dry." Under this program, the City of Aurora paid farmers to install efficient irrigation systems. Payments ($1,400/acre) covered the cost of drip irrigation infrastructure system or portion of an overhead sprinkler, and participating farmers were required to switch to crops with lower consumptive use, so that saved water could be transferred to municipal uses. This project generated measurable water savings, while also assisting farmers to increase the WUE, IWE and IE on their operations, since drip irrigation allows farmers to practice regulated deficit irrigation (RDI). This is the practice of regulating or restricting the availability of water in the soil until a level of plant water stress is attained in order to improve fruit quality and control canopy growth. One outcome of RDI is to increase WUE, consistent with the "quality-driven" incentive that motivates interest in new irrigation practices, since the improved systems give producers the opportunity to improve the value of their crops, switch to higher-profit alternative crops, or both.

Goal-Alignment Under Multiple Funding Programs

Another of the lessons learned by the NCB Partnership is that the goals of various funding programs do not always align to support the approach of increasing WUE, IWUE and IE. In some respects, when successfully implemented water efficiency practices and associated benefits can blur the lines between ATM, DCP and WUE projects that are not fully aligned. Water resource funding, for example, tends to support outcomes that primarily reduce consumptive use, whereas agricultural program funding focuses primarily on sustainable and profitable farming. The ATM Support Report highlights the importance of leveraging other funding sources, since ATM projects "*are often motivated by factors beyond the transferred water*" and the CWCB "*should develop and maintain an inventory of alternative funding sources for project applicants to consider*." The NCB Partnership utilized funding from Trout Unlimited and The Nature Conservancy, but the Bureau of Reclamation, Department of Agriculture (USDA) and Natural Resource Conservation Service (NRCS) are additional examples. Given their divergence of priorities, however, these funding sources are not well-suited to independently support programs that build understanding and confidence in the implementation of newer irrigation approaches.

From the perspective of the NCB Partnership, improving WUE, IWUE and IE furthers the goal of water savings (as alternatives to consumptive use transfers), while also achieving the goal of profitable farming. Applied research and implementation projects that serve both of these goals can only be achieved by leveraging matching funds. Goal-aligned projects would take a synergistic approach, supporting on irrigation practices to improve crop quality, farming of low water use alternative crops, and developing profitable, practical and sustainable farm enterprises.

A critical element of goal alignment is having a central fiscal agent that can manage multiple funding sources. Farmer networks are not equipped to handle large and complex grants, and the lack of large crop commodity associations, commissions and organizations in Colorado proves to be an impediment to the coordination of research goals in our state. Other options are available, however given that Colorado has a number of districts that consider agriculture, economics and water as focus areas. The best model for aligning these multiple goals would be to establish a regional research hub supported by CWCB funding, as well as agricultural funding from state NRCS or WSARE sources and local economic development agencies, such as Delta County Economic Development and Montrose County Region 10. The research goals of the hub would be developed and sanctioned with support from water resource management districts or entities that serve local clientele.

Hiring Dedicated Water Use Efficiency Program Manager(s)

The lack of local and available expertise was identified by the NCB Partnership as another major obstacle to the adoption of efficient irrigation approaches. For this project, support and directed assistance was provided largely by Colorado State University. Without this support, the project gains could not have been made and losses may have occurred. For example, in the absence of such direct technical assistance, it was observed in at least one case, a major piece of infrastructure (i.e., a center pivot sprinkler) and local CoAgMet station were actually removed in favor of less efficient practices (gated pipe and furrow irrigation). This backsliding is lamentable but understandable nonetheless without local technical or industry support.

Measurable water savings is unique as a shared goal between water management districts and contract landowners. Recognizing this, the Northern Colorado Water Conservancy District, for example, employs a Water Use Efficiency Program Manager as opposed to simply relying on NRCS Soil Conservation Districts to satisfy the demand for irrigation technology transfer. By focusing exclusively their specific district, this specialist can locally augment the work of over-subscribed NRCS and CSU Extension staff. Support for these program manager positions is based in the understanding that agricultural water is limited, either due to a junior water right status, concerns over compact compliance or the impact of drought, so regular contact with water users and feedback to the district board members is critical. The NCB Partnership similarly recommends having dedicated Water Use Efficiency Program Managers (WUE Program Managers) that are responsive to the board members and landholders of Western Slope water management associations and districts. This recommendation is based on the recognition that building motivation, confidence and understanding in newer irrigation practices requires the expressed support of local and regional water resource management associations. Regular and direct contact with agricultural producers by Water Use Efficiency Program Managers operating with the sanction of water management entities affords these specialists a unique degree of credibility.

There is tremendous progress in the efficiency industry and Colorado citizens accept the importance of water scarcity, use, management and respect. Regional WUE Program Managers would build on this progress by supporting more efficient agricultural water use through education, collaboration, and leadership. For example, the WUE Program Managers could play a significant role in the development formal farmer networks (mentioned later), structured around the specific goal of improving efficiencies in agricultural water use. By supporting projects between public, private, and non-profit organizations, the WUE Program Managers would be a mission-oriented position, working with government, industry and stakeholders to optimize water consumption, improve irrigation performance, and lower costs by disseminating new methods, products, and ideas.

Support Research to Aid Decision Making

Additional research support is always useful in assisting producers to be competitive in the market place. Quality-driven parameters could be an important research thread, considering that they are powerful incentives to encourage efficient agricultural water use and other conservation practices. Other promising research initiatives include market-driven crop switching to lower water use crops (from perennial to annual crops), niche markets and transitioning to organic crops. These farming approaches have proven profitable and often align with natural resource conservation goals (soil health, climate action, etc.) but are significantly more achievable using improved irrigation systems.

On the other hand, it should be highlighted that the "quality driven" concept can be applied to more than just specialty or niche crops. High water use crops of lower relative value can also be irrigated in accordance with quality-driven concepts, even on furrow-irrigated fields. For instance, water-stressed alfalfa is known to have increased crude protein levels, which increased relative feed value (RFV) and relative forage quality (RFQ), which are both terms for quantitative scales that describe animal responses to forage. Studies suggest that there is an optimal water application level in alfalfa production that produces higher RFV/RFQ haylage to be grown with less water without significantly affecting yields (Cabot, et al., 2017). Hay with RFV over 185 is considered to be of supreme quality, and some buyers will pay premiums for higher quality haylage. By encouraging quality-driven incentives for efficient irrigation of crops that have much larger agricultural land footprints, the possibility exists for much greater water conservation and savings under ATM programs. The NCB Partnership would argue that monitoring and verification of consumptive use differences between historical practices versus efficient irrigation, alternative crops, cover cropping and deficit irrigation are high-priority research areas.

5.2 Support Demand Management Program(s)

Another potentially related initiative to the NCB grand vision, is Demand Management (DM); this refers to the ability to control and reduce the depletions or consumptive uses. In the Upper Colorado River Basin (UCRB), Demand Management is based upon the concept of, and potential ability to reduce regional water depletions associated with consumptive use (CU) of the UCRB for the purpose of increasing inflows to Lake Powell.

Although it must be noted that the concepts implicit in DM process is currently undergoing a formal feasibility assessment study being managed by the CWCB and that no formal conclusions have been established at the current time, NCB project results suggest that increased resiliency, flexibility and profitability afforded by increased WUE practices could better enable growers to participate in a DM process that might eventually include partial, rotational, and/or other types of fallowing that are typically associated with a DM process.

It is hoped that the NCB project approach and results can be utilized to inform, support and/or enable, in part, the potential development of a Demand Management when, if and as DM feasibility might be deemed appropriate

Sidebar: *According to the CWCB website: "The Upper Colorado River Basin States are currently investigating the feasibility of a potential Upper Basin Demand Management program. Colorado is initiating a process to investigate feasibility of a potential Demand Management program within the state, on a parallel track to efforts at the interstate level." https://cwcb.colorado.gov/focus-areas/supply/demand-management.*

For instance, support for investments in appropriate types of on- and off-farm infrastructure appropriately utilized to optimally time irrigation rates, will assist in defining the opportunity to reduce water diversions throughout the entire irrigation season and upon which annual and/or perennial crops may be most suitable for reduced diversion at the end of the season with adverse or even improved crop quality.

5.3 Establishment of Formal Farmer Networks

One of the advantages of formal farmer networks, such as the NCP Partnership model, is that their goals and objectives overlap with a number of other funding sources that equivalently express an interest in improving agricultural irrigation efficiency. As identified in the ATM Support Report, some of these collaborative funding sources include: (1) U.S. Bureau of Reclamation WaterSMART Water Marketing Strategy grant program, (2) environmental and conservation non-profit support, and (3) U.S. Department of Agriculture (USDA) and Natural Resource Conservation Service (NRCS) programs. The NCB Partnership also supports more irrigation districts (and by extension, water user associations) being involved in the creation of ATMs, which was identified in the "Alternative Transfer Method Support" report as a barrier that needs to be overcome. By utilizing CWCB funds alone or by leveraging other funding sources, the NCB Partnership identifies the following actions as being critical to the next iteration of the ATM grant program.

Future ATM projects will also be strengthened by formalizing relationships with agricultural advocacy groups, such as the NCB Partnership, that have trusted local connections to water users. Although the NCB project was successful in developing a small network of participating growers interested in new practices guided by soil moisture technologies, there remains a great potential to increase this grower community. The "Alternative Transfer Method Support" report recommends these partnerships as part of the education and outreach objectives of the ATM program. For example, the Environmental Quality Incentives Program (EQIP) is a source of funding included in the Farm Bill that helps the NRCS partner with farmers to invest in solutions that conserve natural resources, but irrigation water management (IWM) is just one component of many in EQIP and the goals of this program do not necessarily align with the objectives or urgency of the CWCB, such as the need for measurement and verification of impacts regional impacts. Additionally, while EQIP may supply the physical technology to individual farmers, a lesson of the NCB Partnership is that formal farmer networks are needed to help farmers understand and develop confidence in using more sophisticated irrigation technology.

The Nebraska Agricultural Water Management Network (NAWMN) is an organization worth examining as a possible model for what could work in an area like the Uncompahgre. The NAWMN (https://water.unl.edu/category/nawmn) was established to promote technology implementation through a network of farmers, university Extension and Engagement offices, NRCS, crop consultants, and other stakeholders in response to the water management challenges of the Ogallala Aquifer. Since its initiation in 2005, the NAWMN has grown to over 1,400 participants, spread over multiple counties in Nebraska. The example of the NAWMN provides several elements of success explain that should be utilized to establish similarly impactful networks in Colorado.

First and foremost, these networks must be organized around a central purpose. The NCB Partnership admittedly struggled at times with its mission and goals, which is not unusual for a farmer network in its infancy faced with multiple pressing issue.

Secondly, the network needs regular contact with a WUE Program Manager that serves as a liaison between local farmers, water managers and landholders who have enrolled into the concept of the purpose of the network. The 2018 follow-up survey indicated that knowledge of local farmers was important and as discussed in section 5.1, there is a demonstrated need for local expertise to support the implementation, operation and maintenance of irrigation efficiency practices. A program manager or paid liaison operating with the sanction of the regional water management association would instill confidence and simultaneously support the growth of the farmer network.

5.4 Engagement of Industry Partners

As farmer networks grow and associated WUE projects expand in the NCB focus area and across the Lower Gunnison Basin, it is essential to engage with industry partners that not only make new irrigation technologies available, but to support them after installation. The NCB partnership learned some difficult lessons regarding the proper operation and maintenance of soil moisture monitoring tools that could have been avoided with local industry support. Although some motivation existed to apply these tools, the difficulties in understanding the equipment directly led to a lack of confidence and thus diminished interest and participation. In particular, better technical support for these tools are needed, if not required, from the manufacturers of environmental monitoring equipment. Since farmers are not inclined to call technical support hotlines and wait on hold for assistance, they will normally go to local suppliers of irrigation and monitoring equipment for assistance. These local suppliers, therefore, need expertise and training to troubleshoot problems that arise when using irrigation and monitoring tools with which they are not highly familiar.

Additional support from local distributors and vendors is key to expanding adoption rates tools to improve efficiency. In fact, cooperative projects that involve public, private partnerships with assistance from non-profit organizations, as appropriate. is key to overcoming technological challenges associated with new monitoring methods that can support the reduced over application of water, improved production, and reduced costs.

5.5 Engagement of Water Providers and Integration with Users

Traditionally, irrigation water providers, including water user associations, irrigation districts and mutual ditch companies (e.g., UVWUA, Fire Mountain Canal and Reservoir Company in the No Chico Brush Project area) deliver irrigation water from commonly-owned conveyance structures, such as canals and laterals, to specific locations, such as headgates, turnouts and associated sub-ditches and laterals that are privately owned.

In other words, the ‘responsibility of the water providers” ends at the delivery point. From there, water shareholders and landowners are typically responsible for getting the irrigation water to their fields and areas of application. Unfortunately, this can often result in a “solution gap” at this point of intersection. This is an opportunity for engagement and integration of for “bridging the headgate”.

For the No Chico Brush grand vision to be successful and to optimize the benefits of irrigation water efficiency, it is essential to integrate the entire system. Without a comprehensive approach that includes the end water user, conveyance improvements and investments such as pressurization can be lost. If the end user is not involved in planning and design and for instance, the sub-lateral is unable to take advantage of the pressure potential created by ditch piping project, the system may not realize the full potential.

A famer-led dialogue, such as NCB should be employed to maximize the benefits, especially for tax payer funded WUE projects. An effective entity should be set up to support the network of activities and army of locally driven people to organize around the issues of water supply / demand and sustainability.

5.6 Engagement of Water Policy Agencies

It is important that NCB project findings be used as a tool to engage with water policy makers. Project results and findings should provide guidance and assistance with funding prioritization and decisions. This project demonstrates that use and expansion of the NCB Grand Vision is consistent with Colorado Water Plan and Technical Update and as such could and should be used by CO DNR and CO DWR to gain policy and financial support for proactive WUE solutions.

For example, as previously stated, it is important to recognize that WUE improvement projects as described in this report, can and should serve as an ‘Alternative to ATMs”. Improving agricultural WUE projects is often an overlooked technique to increase sustainability of irrigated agriculture in western Colorado and specifically to address the “Gunnison Basin predicament”.

List of Figures

Section 2

Fig 2.1 Map of NCB Irrigation Evaluation and Pilot Technology Evaluation Sites

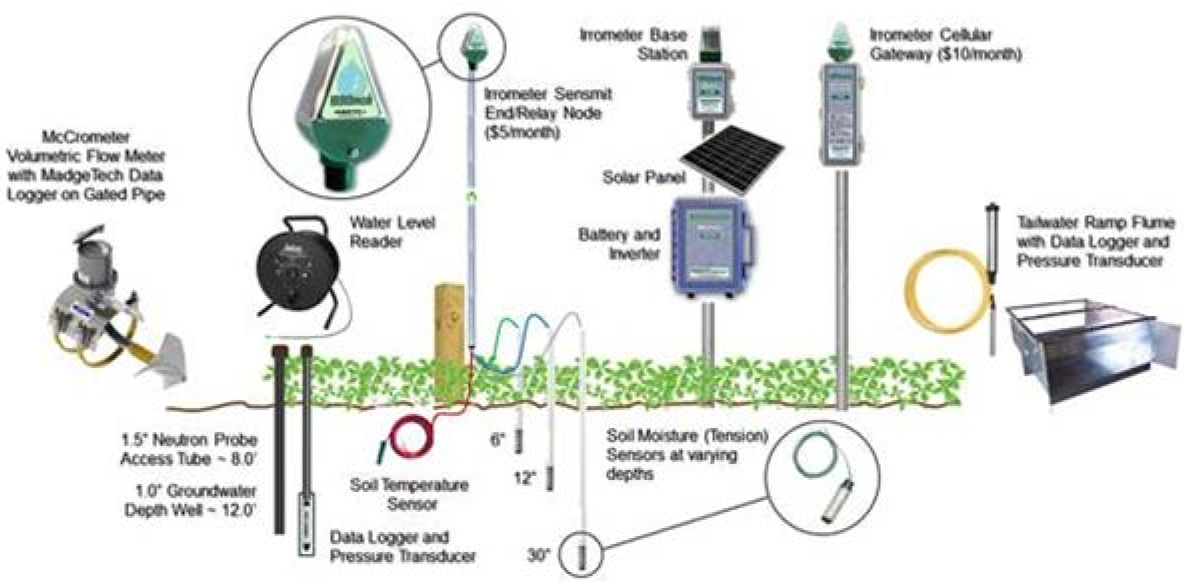


Figure 2.2: Instrumentation for Irrigation Evaluation Sites

Section 3

Figure 3.1:

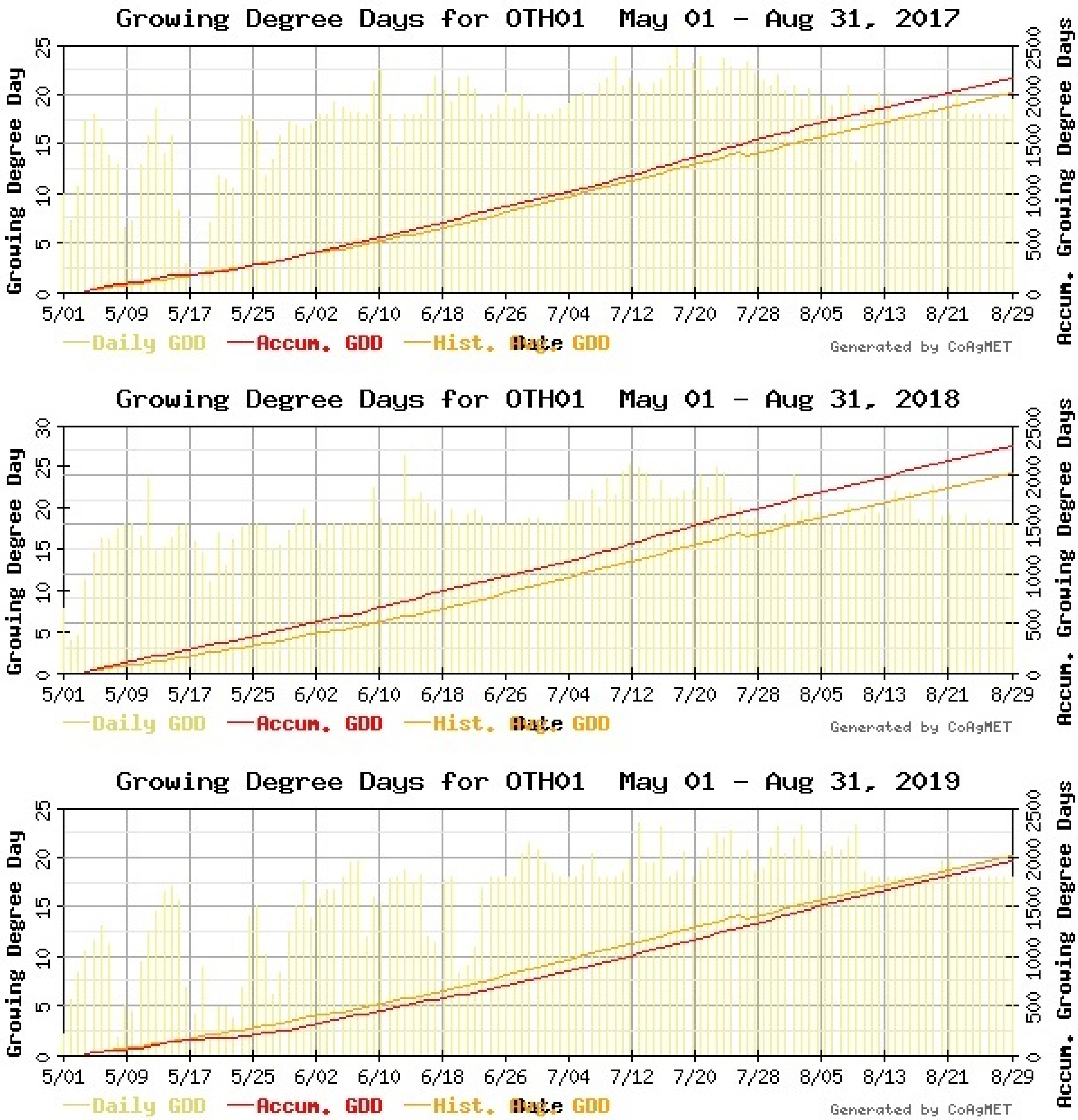


Figure 3.2:

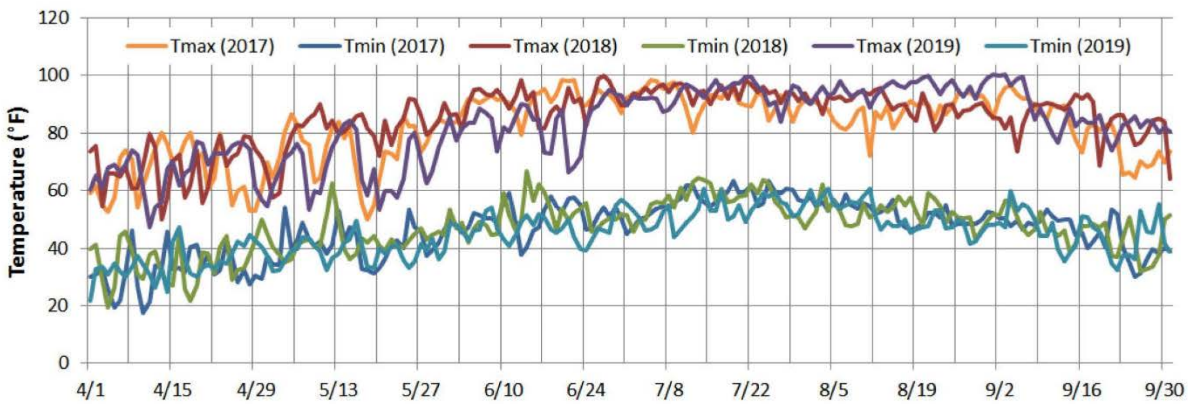
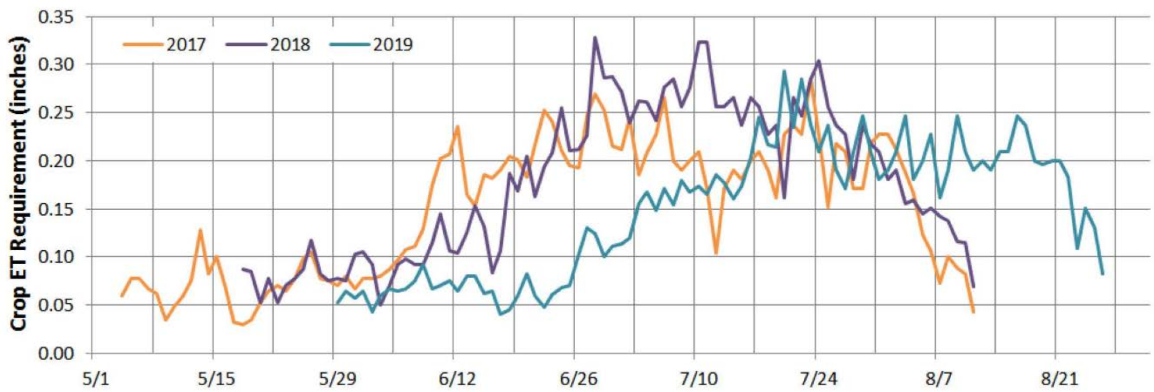


Figure 3.3:



Crop water use totals for 2017, 2018 and 2019 were estimated at 15.0, 15.2 and 13.4 inches during the period between planting and harvest for each season for our study.

Figure 3.4a:

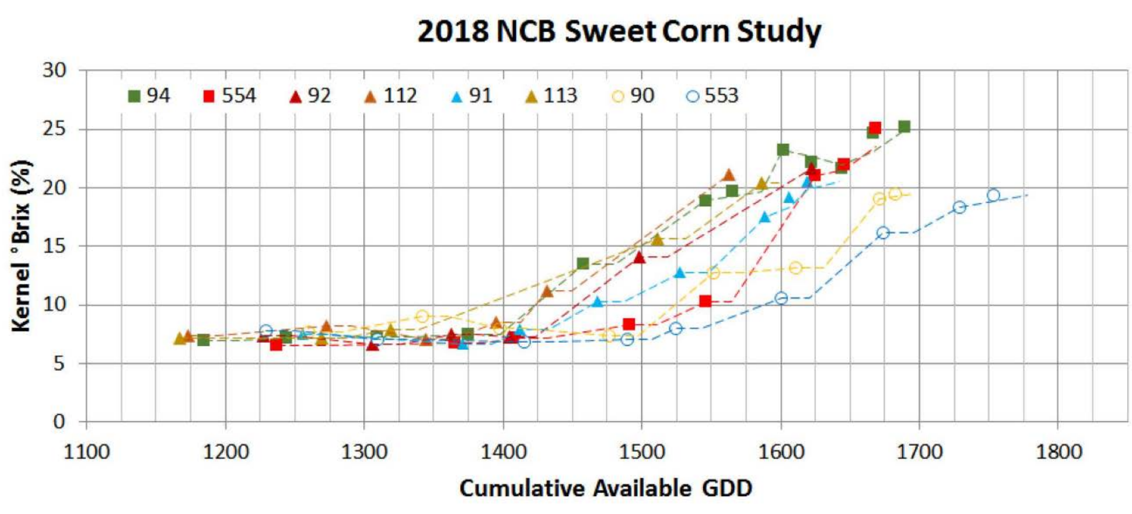


Figure 3.4b:

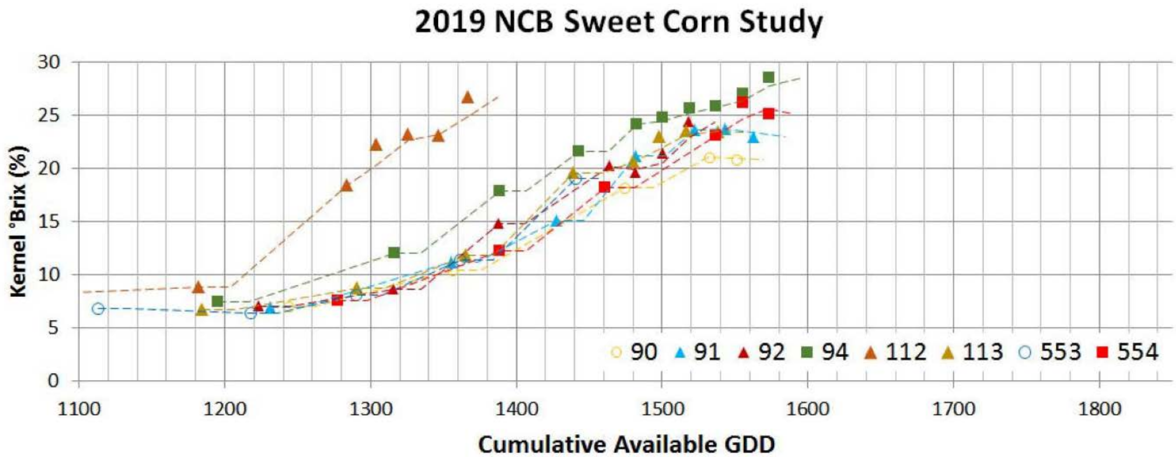
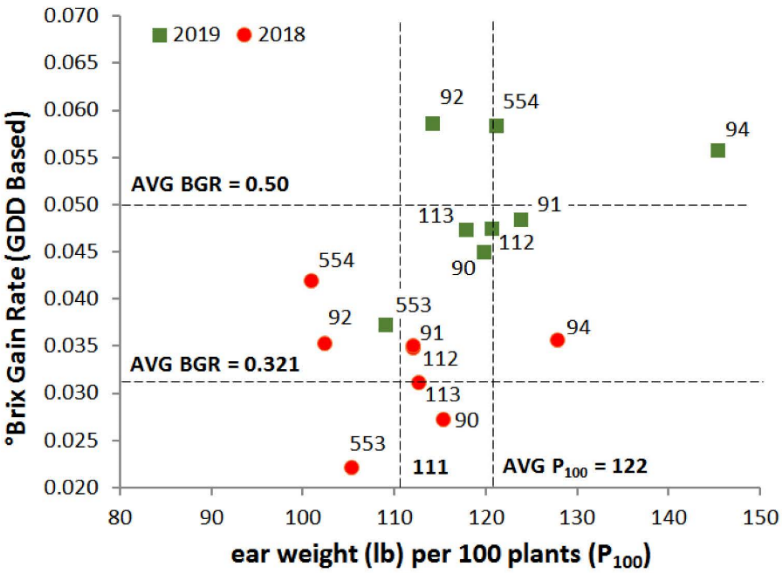

2019 NCB Sweet Corn Study
Kernel °Brix (%)
30
25
20
15
10
5
0
1100
1200
1300
1400
1500
1600
1700
1800
Cumulative Available GDD
90 91 92 94 112 113 553 554

Figure 3.5



■ 2019 ● 2018
°Brix Gain Rate (GDD Based)
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
AVG BGR = 0.50
AVG BGR = 0.321
111
AVG P100 = 122
92
554
94
91
113
112
90
554
553
92
91
112
113
90
553
94
80
90
100
110
120
130
140
150
ear weight (lb) per 100 plants (P100)

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